JOURNAL of the AMERICAN SOCIETY *of* *NAVAL ENGINEERS* Inc.

November, 1961

Volume 73 Number 4

Presidents of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

REAR ADMIRAL M. J. LAWRENCE, US NAVY, President

Past Presidents

1889-90 *Chief Engineer Nathan P. Towne, U. S. Navy*
1891 *Past Assistant Engineer G. W. Baird, U. S. Navy*
1892 *Chief Engineer David Smith, U. S. Navy*
1893-94 *Chief Engineer H. Webster, U. S. Navy*
1895 *Chief Engineer James H. Perry, U. S. Navy*
1896 *Chief Engineer E. D. Robie, U. S. Navy*
1897 *Chief Engineer David Smith, U. S. Navy*
1898-99 *Chief Engineer H. Webster, U. S. Navy*
1900 *Commander H. Webster, U. S. Navy*
1901-02 *Commander C. W. Rae, U. S. Navy*
1903 *Lieutenant Commander W. M. Parks, U. S. Navy*
1904 *Rear Admiral John D. Ford, U. S. Navy*
1905 *Commander A. F. Dixon, U. S. Navy*
1906 *Commander A. B. Canaga, U. S. Navy*
1907 *Commander B. C. Bryan, U. S. Navy*
1908 *Commander R. S. Griffin, U. S. Navy*
1909 *Rear Admiral John K. Barton, U. S. Navy*
1910-11 *Engineer-in-Chief H. I. Cone, U. S. Navy*
1912-13 *Captain R. S. Griffin, U. S. Navy*
1914 *Rear Admiral J. R. Edwards, U. S. Navy*
1915 *Captain S. S. Robison, U. S. Navy*
1916 *Captain C. W. Dyson, U. S. Navy*
1917-18 *Captain H. P. Norton, U. S. Navy*
1919 *Rear Admiral H. P. Norton, U. S. Navy*
1920 *Rear Admiral C. W. Dyson, U. S. Navy*
1921 **Captain A. J. Hepburn, U. S. Navy**
1922 *Rear Admiral C. W. Dyson, U. S. Navy*
1923-24 *Captain J. T. Tompkins, U. S. Navy*
1925 *Rear Admiral C. F. Hughes, U. S. Navy*
1926 *Rear Admiral M. M. Taylor, U. S. Navy*
1927 *Rear Admiral John Halligan, U. S. Navy*
1928 *Captain E. L. Bennett, U. S. Navy*
1929-30 *Rear Admiral H. E. Yarnell, U. S. Navy*
1931 **Rear Admiral S. M. Robinson, U. S. Navy**
1932 *Rear Admiral F. B. Upham, U. S. Navy*
1933 *Rear Admiral William A. Moffett, U. S. Navy*
1933 *Rear Admiral E. J. King, U. S. Navy*
1934-36 **Rear Admiral William H. Standley, U. S. Navy**
1937 **Rear Admiral Alfred W. Johnson, U. S. Navy**
1938 **Rear Admiral Harold G. Bowen, U. S. Navy**
1939 **Rear Admiral S. M. Robinson, U. S. Navy**
1940 **Rear Admiral Henry Williams, U. S. Navy**
1941 *Captain Claud A. Jones, U. S. Navy*
1942 **Rear Admiral Herbert S. Howard, U. S. Navy**
1943 *Rear Admiral J. J. Broshek, U. S. Navy*
1944 *Rear Admiral C. L. Brand, U. S. Navy*
1945 **Rear Admiral E. W. Mills, U. S. Navy**
1946 *Rear Admiral Harvey F. Johnson, U.S.C.G.*
1947 **Rear Admiral C. W. Styer, U. S. Navy**
1948 **Rear Admiral Roger W. Paine, U. S. Navy**
1948 *Rear Admiral Harvey F. Johnson, U.S.C.G., Ret.*
1949 **Rear Admiral T. A. Solberg, U. S. Navy**
1950 **Rear Admiral F. E. Haeberle, U. S. Navy**
1951 **Rear Admiral David H. Clark, U. S. Navy**
1951 **Rear Admiral Louis Dreller, U. S. Navy, Ret.**
1952 **Rear Admiral T. C. Lonnquest, U. S. Navy**
1953 **Rear Admiral Homer N. Wallin, U. S. Navy**
1954 *Rear Admiral Evander W. Sylvester, U. S. Navy*
1955 **Rear Admiral W. D. Leggett, Jr., U. S. Navy**
1955 **Rear Admiral F. R. Furth, U. S. Navy**
1956 **Rear Admiral Kenneth K. Cowart, U.S.C.G.**
1957 **Rear Admiral Albert G. Mumma, U. S. Navy**
1958 **Rear Admiral Leroy V. Honsinger, U. S. Navy**
1959 **Rear Admiral William A. Dolan, U. S. Navy**
1960 **Rear Admiral Robert E. Cronin, U. S. Navy**
1961 **Rear Admiral E. H. Thiele, U.S.C.G.**

*Names in italics deceased

JOURNAL

of

The American Society of Naval Engineers, Inc.

PUBLISHED QUARTERLY

UNDER THE SUPERVISION OF THE COUNCIL

Rear Admiral M. J. Lawrence, USN, President

Captain Edward J. Fahy, USN

Mr. Harold H. Hill

Captain Frank C. Jones, USN

Commander Ralph S. Lorimer, USNR

Lieutenant Commander C. P. Roane, USNR (Ret.)

Rear Admiral Floyd B. Schultz, USN

Captain Gilbert F. Schumacher, USCG

Commander Joe W. Thornbury, USN

Mr. C. Swan Weber

Captain J. E. Hamilton, USN (Ret.), Secretary-Treasurer

SEVENTY-THIRD YEAR

VOLUME 73 NOVEMBER 1961 NUMBER 4

Published Quarterly at Washington, D.C., by The American Society of Naval Engineers, Inc.

Entered as Second Class Matter at the Post Office at Washington, D.C., and at Nashville, Tenn. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 3, 1918.

The subscription price of the JOURNAL, postpaid to points in the United States and possessions is $12.00. Single copies, $3.00. To other countries, $20.00. Single copies, $5.00. All subscriptions payable in advance.

Make checks, drafts and postal money orders payable to THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Advertising rates will be furnished on application.

Addresses will be changed at any time, but only upon notification. Immediate notice should be given of any delay in the receipt of the JOURNAL.

Address all communications for the Society to

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Suite 403,Continental Building
1012 14th Street, N.W.
Washington 5, D.C.

The American Society of Naval Engineers, Inc., has no official connection with the Navy Department.

TABLE of CONTENTS

Secretary's Notes 643

Exotic Power Sources
by COMMANDER JOE W. THORNBURY, USN 647

The Bath Iron Works
by MR. JOHN R. NEWELL 655

Some Aspects of Automation for Ships
Philadelphia Section, S.N.A.M.E. 665

Colidar—The New 'Light Look' in Radar
Vectors, Second Quarter 1961 681

Navy Leadership in the Development of Radio Communication
by MR. DONALD JAMES 685

Underwater Technology Needs in Review
Undersea Technology, July/August 1961 693

Marine Engineering Notes from The Soviet Press
by COMMANDER BERNARD M. KASSELL, USN (Ret) 697

A 7500 SHP Gas Turbine for Naval Boost Propulsion
The Marine Engineer and Naval Architect, May 1961 709

Understanding Automatic Combustion Control
by S. G. BRALEWSKI 715

The Automatic Control of Naval Boilers
The Shipbuilders and Marine Engine Builder 719

Experience With Hardened and Ground Gearing in the Royal Canadian Navy
Transactions of the Institute of Marine Engineers (Canadian Division) June 1961 727

Experimental Program for a Plasma Pinch Space Engine
by IRVING GRANET AND WILLIAM J. GUMAN 745

Electromagnetic Compatibility
Frontier, Summer 1961 issue 763

The Design of Heat Exchange Systems Using Graphs and a Mechanical Computer
by HILBERT SCHENCK 767

Estimating Steam Requirements (in Pounds) to Raise Pressure in a Pressure Vessel
by R. KAUFMAN AND A. SEGALO 773

Reinforced Plastics for Hydrospace Vehicles
Society of Aerospace Material and Process Engineers 775

Design, Model Testing and Application of Controllable Pitch Bow Thrusters
by LENNART PEHRSSON AND ROBERT G. MENDE 787

Superconductivity
General Electric Research Laboratory Bulletin, Winter 1961 Issue 797

Shipbuilding Costs can be Reduced
Marine Engineering/Log, May 1961 803

DEPARTMENTS

Local Chapters 809

Changes in Membership 811

Deaths 812

Index to Advertisers 813

Books Received and Paper Review 814

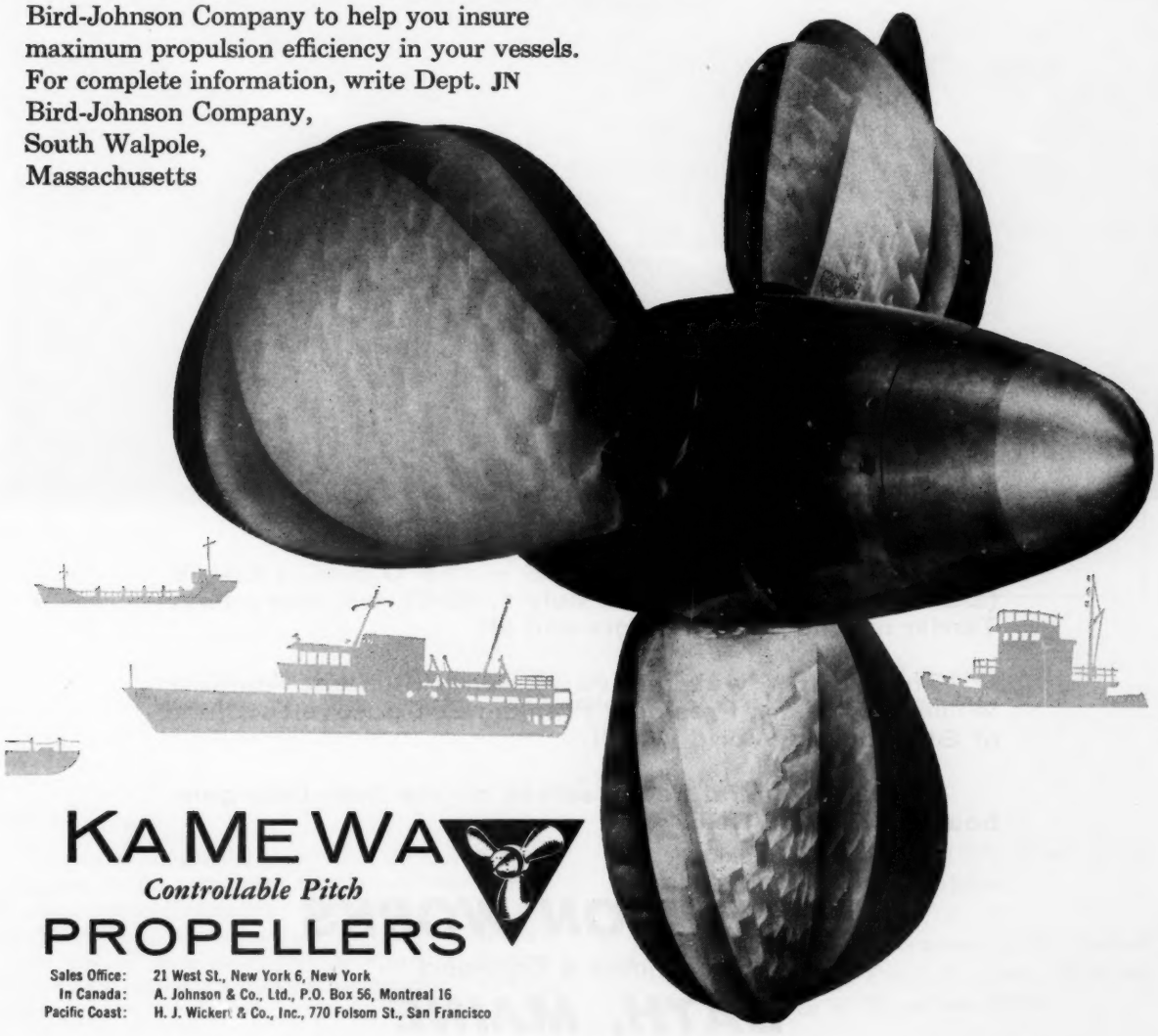
Association Notes 815

KaMeWa

LEADS
THE FIELD

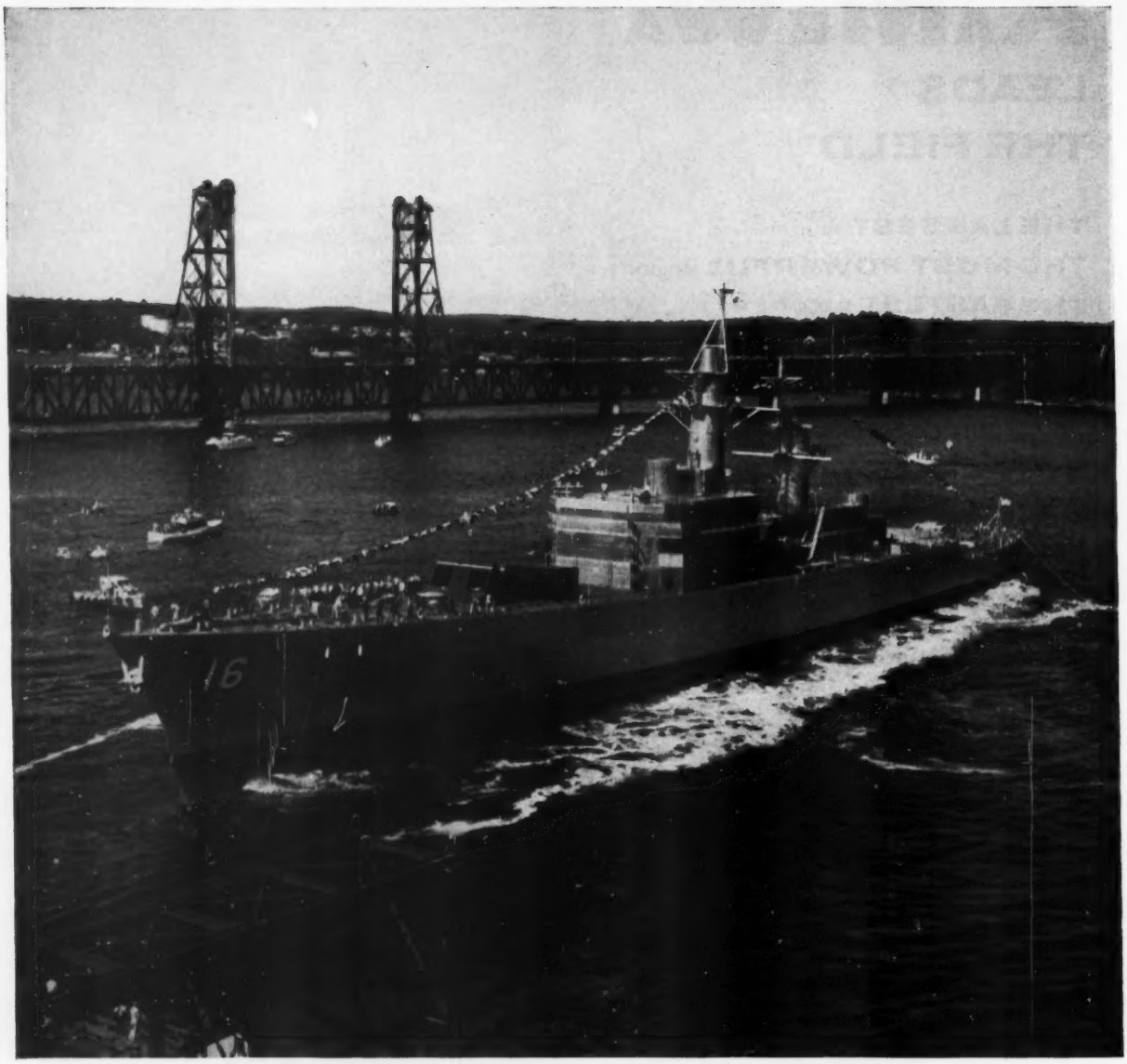
THE LARGEST 19 ft. diameter
THE MOST POWERFUL 20,000 H P
THE FASTEST 2,000 R P M
THE MOST UNITS Over 500 now in service
THE WIDEST RANGE from 200 to 20,000 H P
THE MOST EXPERIENCE Pioneers in C P development since 1937

The advantages of KaMeWa controllable pitch propellers have been proved out in more than 500 world-wide installations. This unmatched breadth and depth of experience is available through Bird-Johnson Company to help you insure maximum propulsion efficiency in your vessels. For complete information, write Dept. JN
Bird-Johnson Company,
South Walpole,
Massachusetts



KA ME WA
Controllable Pitch
PROPELLERS

Sales Office: 21 West St., New York 6, New York
In Canada: A. Johnson & Co., Ltd., P.O. Box 56, Montreal 16
Pacific Coast: H. J. Wickert & Co., Inc., 770 Folsom St., San Francisco



FIRST OF A NEW CLASS – the U.S.S. LEAHY (DLG16), launched at Bath July 1, 1961, will carry twin Terrier missile launchers fore and aft.

The LEAHY was named in honor of Fleet Admiral William D. Leahy, President Franklin D. Roosevelt's Chief of Staff during World War II.

In 1899 Admiral Leahy served on the Bath-built gunboat U.S.S. CASTINE.

BATH IRON WORKS

Shipbuilders & Engineers

BATH, MAINE

Copyright 1961, by the American Society of Naval Engineers, Inc.

Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 73 NOVEMBER 1961 NUMBER 4

Statements contained in articles herein are the private opinions and assertions of the writers and should therefore not be construed as reflecting the views of the AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., nor of any other organization with which such writers are affiliated. The Society as a body is not responsible for statements made by individual members.

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published)

Rear Admiral M. J. LAWRENCE, USN, President

Captain EDWARD J. FAHY, USN
Mr. HAROLD H. HILL
Captain FRANK C. JONES, USN
Commander RALPH S. LORIMER, USNR
Lieutenant Commander C. P. ROANE, USNR (Ret.)
Rear Admiral FLOYD B. SCHULTZ, USN
Captain GILBERT F. SCHUMACHER, USCG
Commander JOE W. THORNBURY, USN
Mr. C. SWAN WEBER

Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer

NAVAL ENGINEERING

Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

SECRETARY'S NOTES

1962 Election

The names of candidates for office which had been proposed by the committee which had been named to make these nominations were presented to the annual meeting in the manner specified in the By-Laws and in each case were accepted on motion duly make, without additional nominations, as follows:

For President in 1962

Rear Admiral R. K. James, USN, Chief of the Bureau of Ships Navy Department

For two regular naval members of the Council to succeed Captain Frank C. Jones, USN and Commander Joe W. Thornbury, USN

Captain John W. Dolan, Jr., USN, Shipbuilding Assistant, Design, Shipbuilding & Fleet Maintenance Div., Bureau of Ships, Navy Department

Captain John H. McQuilkin, USN, Director, Ship Design Branch, Bureau of Ships, Navy Department

Captain J. A. Obermeyer, USN, Commanding Officer and Director of David Taylor Model Basin

Captain H. B. Reece, USN, Deputy Chief, Office of Industrial Relations, Navy Department

Captain W. D. Roseborough, Jr., USN, Branch Head, Submarine Branch Bureau of Ships, Navy Department

For one reserve officer member of the Council to succeed Commander Ralph S. Lorimer, USNR:

Commander C. M. Featherstone, Jr., USNR, Washington Representative, Northrop Corporation

Commander Walter D. Sharp, USNR-R, Head Engineer, Steam Turbines and Gear Branch, Bureau of Ships, Navy Department

For one civilian member of the Council to succeed Mr. H. H. Hill

John W. Chandler, Branch Manager, York Corporation

F. J. Lindauer, Manager, Fairbanks Morse & Company

Robert B. Nation, Manager, International Nickel Company

Ballots for the election will have been in the hands of members for several weeks. It is hoped that there will be a very heavy return. The form of ballot which was introduced last year was adopted to simplify your voting as much as possible.

Society Progress

Progress as a technical society during the last year is well described in the following statement which was made to the members who attended the annual meeting which was held in the Navy Department on 10 October 1961:

At the annual meeting one year ago, the most significant thing which occurred was stated in the minutes as follows:

"Mr. Uriah L. Allen, Jr. made an appeal for strong consideration of adding at least one technical meeting each year to the Society's calendar. He stated that the Society was becoming thought of as a social rather than technical society. The President stated that this matter would be added to the Council's calendar of unfinished business."

It is significant that among those who heard Mr. Allen's appeal were Mr. Walter Flinn and Rear Admiral E. H. Thiele, USCG. Admiral Thiele became President of the Society for 1961 and from the beginning of his regime pressed consideration of Mr. Allen's suggestion.

Local Chapters

However, Mr. Allen did not wait for Council action but almost at once took the first step toward accomplishment of what he had in mind. Within five months of the annual meeting, Mr. Allen took advantage of a provision which had been written into the By-Laws ten years before and organized the first ASNE local chapter. Instead of the 20 members which are required to found a local chapter, he assembled 36 and received the first charter of a local chapter as was described in the May issue of the Journal. This, the Flagship Section, held its organizational meeting in June. On 3 October, less than one year after the original suggestion, the Flagship Section held its first technical meeting which is reported in the Local Chapter section of this Journal.

Stemming directly from the Flagship Section, members in Honolulu, T. H., New York, N. Y. and Houston, Texas have expressed interest in forming additional local chapters. It is hoped that this enthusiasm will continue and will expand until the Society's chapters blanket the United States.

Technical Meetings

While the above was going on, Mr. Flinn, who is also a member of the Society of Automotive Engineers, realizing the administrative difficulties which attend the arrangements for a national technical meeting, proposed that such a meeting be arranged jointly between SAE and ASNE. This would make the experience for SAE for holding such meetings, available at essentially no cost to this Society. Mr. Flinn obtained agreement of the SAE to the proposed joint meeting and later our own council approved.

The details of the joint meeting are yet to be worked out. The meeting will be held at the Sheraton-Park Hotel in Washington, D.C. on April 8th to 11th, 1963. Full details will be made available to our membership as soon as they are worked out. Since the ASNE annual banquet is scheduled for 3

May 1963, these two affairs will not interfere with each other. It is felt that our banquet has a flavor which is unique and that it should not be affected by the addition of technical sessions.

In the meantime we have conducted correspondence with the Professional Group on Underwater Technology of the American Society of Mechanical Engineers which may lead to joint technical meetings with this organization at some future date.

Professional Meetings

At the first Council Meeting following the 1960 annual meeting President Thiele suggested the possibility of a quasi-technical meeting which might feasibly be arranged much more easily than a true technical meeting might. The program which he suggested was aimed at the management and executive level rather than at the practicing engineer whose technical interests are the matter of real concern at a true technical meeting.

Admiral Thiele's idea was accepted by the Council and has been pressed so expeditiously by President Lawrence, that such a meeting is now assured for 1962. This meeting will be held on the day of the banquet. Friday, 4 May 1962, at the same location, the Statler Hilton Hotel in Washington.

The program will be:

12:00 noon Luncheon with the Honorable James H. Wakelin, Assistant Secretary of the Navy (Research and Development) as speaker

2:00 p.m. (approximately) An afternoon session of about two hours with Vice Admiral Roy Gano, USN, Commander MSTS and Rear Admiral R. K. James, USN, Chief of the Bureau of Ships as speakers.

The exact titles of the three speaker's talks are not yet known but the general theme will be "The Navy's Technical Progress through 1961 and Prospects for the Future".

When the 1962 banquet announcements go out each member will be given an opportunity to purchase as many tickets for the luncheon as he wishes. There will be no restrictions on who may attend but only members may buy tickets. The price will be announced later. Also each member will be offered as many tickets, at no price, as he wishes for the afternoon session. There will be no restrictions as to who may attend the afternoon meeting except that admission will be by ticket only.

The arrangements for the 1962 meeting have been firmed up and those for 1963 will go forward as rapidly as necessary and as conditions permit. Continuance of either type of meeting will hinge very largely on the members' acceptance and attendance at the two premiers.

It is believed that the Council with the individual contributions of Mr. Allen and Mr. Flinn has registered a remarkable accomplishment in the year between two annual meetings. The future character of the American Society of Naval Engineers will depend to a great extent on the response to the 1962 Professional Meeting and to the 1963 Joint ASNE-SAE Technical Meeting.

Underwater Technology Symposium

We mentioned above, correspondence with the Underwater Technology Professional Group of the American Society of Mechanical Engineers and that this might lead to joint technical meetings of our Society with this group. Since the group was only organized in January 1961, the following notice is a good indication of its strength and of the importance of its field of interest:

"An Underwater Technology Symposium and Technical Program is planned as part of the Annual Winter Meeting of the ASME in New York this fall (29 November 1961). The symposium is sponsored by the newly founded ASME Professional Group on Underwater Technology. Dr. George F. Wislicenus, Director of the Ordnance Research Laboratory, Penn State University, is the Chairman of the symposium. Interesting technical papers have been selected for presentation at the technical sessions, and noted authorities will speak. Vice Admiral William F. Raborn, USN, Director of the Special Projects Office, Bureau of Naval Weapons, Dr. H. E. Sheets, Chief Research and Development Engineer at Electric Boat Division, General Dynamics Corporation, Groton, Connecticut and Dr. Paul M. Fye, Director of Woods Hole Oceanographic Institute, are the principal speakers for the symposium. Dr. Harvey Brooks, Dean of the Engineering and Applied Physics Division at Harvard University will be the luncheon speaker."

Mrs. Helen Brand

With deep regret we report the death of Mrs. Helen Brand, widow of our late past-President Rear Admiral Charles L. Brand, USN. It was Mrs. Brand who established the ASNE Brand Award which is now a permanent annual award of the Society.

Correction

In announcing the Brand Award for 1961 on page 436 of the JOURNAL of August 1961, we stated that the marks attained by Lieutenant Broughton in standing first in Course XIIIA at MIT were the highest ever attained. This statement is an interpretation of the editor and is incorrect. Lieutenant Broughton's academic record was outstanding but his marks have been exceeded slightly by several previous officer students in this course. In recent years, two of these, E. L. Perry, USCG who graduated in 1946 and V. K. Atkins who graduated in 1948 completed the course with perfect academic records.

FLAGSHIP SECTION ASNE

(See also page 810)

The Society's first local chapter, the Flagship Section, which is located in the Annapolis, Baltimore, Washington area has set a goal of 200 members by the end of 1962. Members of the ASNE in any category are invited to address a letter of application for chapter membership to

Mr. Herbert F. Hathaway
c/o General Electric Co.
111 Park Avenue
Baltimore 1, Maryland

Others who are interested are urged to seek ASNE membership to qualify them for the Flagship Section.

Annual dues of the Flagship Section are $2.00

Applicants will be admitted when their application is approved and dues for the remainder of 1961 will be only $1.00. For non-Society members, Mr. Hathaway will process Society applications as well as for the chapter or they may apply directly to the Society offices.

The Flagship Section will schedule a minimum of four technical meetings a year. The first of these is reported on page 810 of this Journal. The next one will be held on—

5 December 1961 at 8:00 p.m.
in the
Potomac Electric Power Company Auditorium,
11th & E Streets, Washington, D. C.

All Society members and their guests are invited. The speaker will be Dr. Gene Strull, Manager Solid State Advanced Development Laboratory, Westinghouse AirArm Division. His subject will be "Molecular Electronics".

ULTRAHIGH MAGNETIC FIELDS

The feasibility of producing extremely high magnetic fields with superconducting solenoid magnets has been demonstrated by Bell Telephone Laboratories. A superconducting compound of niobium and tin (Nb_3Sn), fabricated and reacted by special metallurgical techniques, was utilized in the latest experiment. This compound was first discovered at Bell Labs in 1954.

Although it has been realized for many years that it is possible to produce magnetic fields with superconducting solenoids, the materials that have been tried in the past would only sustain fields of a few thousand gauss. At larger magnetic fields the superconducting properties disappear. With the new compound, steady-state magnetic fields of 88,000 gauss are possible.

Indications are that the niobium-tin material will sustain fields of 100,000gauss while carrying electrical currents of 100,000 amp per sq cm of cross section.

Mechanical Engineering, May 1961

CONTINUOUSLY OPERATING OPTICAL MASER

The optical gas maser—an approach to light amplification entirely different from the solid-state masers recently announced by Hughes Aircraft Company and Bell Telephone Laboratories ("Mechanical Engineering," September, 1960, p. 75; and December, 1960, p. 72)—has been demonstrated by Bell Labs. It was the result of a "planned scientific discovery."

The new maser uses a mixture of helium and neon gas to achieve continuous operation and the power required is only in the tens-of-watts range. Previous optical masers—built around crystals—required thousands, even millions of watts of power to transmit large bursts of visible light of very short duration.

Mechanical Engineering, May 1961

COMMANDER J. W. THORNBURY, USN

EXOTIC POWER SOURCES

THE AUTHOR

graduated from the United States Naval Academy in 1943. After service in the USS MISSISSIPPI and USS PHILADELPHIA, he was assigned to post-graduate instruction at the Massachusetts Institute of Technology, receiving the Naval Engineer degree in 1949. He subsequently served at Norfolk Naval Shipyard, on the staff of Commander Service Squadron 3 and at Puget Sound Naval Shipyard. Immediately prior to his present duty station, he was assigned for three years as Associate Professor of Naval Engineering at the Massachusetts Institute of Technology. He is presently Head of the Electrical Branch, Bureau of Ships. He is a member of the American Society of Naval Engineers, the Society of Naval Architects and Marine Engineers and Sigma Xi.

"This article is the first technical paper presented at the first technical session of the first local chapter of the Society."

INTRODUCTION

IT HAS BEEN SAID, only partly in jest, that "exotic" is a synonym for "expensive". It is not in this sense but in the more accurate one of "unusual" or "foreign" that the word is used in the title of this paper. Further, only those power sources which have possible marine applications will be considered. Such devices as the ion propulsion engine while perhaps useful in outer space have litttle significance for powering ships on the oceans of the earth. Nuclear power has already proven to be a spectacular performer in improving endurance and predictions for a bright future have been many. Since there are already practical operating nuclear systems even though there are many more possible but untried variations, it will not be considered here. Neither will fission power's sister development, fusion power, be discussed since controlled fusion has not been demonstrated. This paper, then is limited to new power sources not now being used in ships but which might possibly be used in marine main propulsion plants in the future, and is further limited to systems which have already produced controlled power even though in limited amounts and of short duration.

Throughout the years, marine propulsion has evolved from dependency on oars or sails to dependency on heat engines. Only insignificant amounts of other energy sources are used today in the propulsion of ships. Since the first installation of a heat engine in a ship, there has been a con-

tinual striving toward increased efficiency. The motivation is obvious. If efficiency is increased more power can be packed into the same space, less fuel is required for the same shaft output (with consequent saving in fuel costs) and since less fuel is required for a given output, storage space required in the ship for fuel can be reduced and more cargo carried.

The most efficient cycles now operable are those of large central electric power stations. Maximum thermodynamic efficiencies of 40 to 42 per cent are currently being achieved in the most modern fossil fuel plants. Thermal efficiency improvement over the next decade or two in these plants has been realistically appraised at raising the level to only about 45 per cent unless entirely new conversion processes are used. Since marine plants cannot take advantage of extensive heat reclaiming equipment used in shore practice because of space and weight limitations, the efficiency of marine propulsion plants* do not approach those of shore plants. Marine plants might also expect to better present performance in about the same proportion as shore plants—that is, gradual but disappointingly slow progress can be predicted.

All power production begins with stored energy in some form. For ship propulsion, this stored energy must be converted into mechanical energy at the shaft. Heat engines take the stored energy in a fuel, convert this to heat energy and then convert the heat energy to mechanical energy. In converting the heat energy to mechanical energy, the theoretical maximum efficiency is limited by Carnot cycle considerations. The various losses (such as mechanical friction and extraneous heat losses) reduce the actual efficiency to a figure somewhat lower. Any new power source in order to be attractive, must improve on present day practice. To achieve any substantial improvement, a better Carnot efficiency must be achieved or a power source not dependent on thermodynamic cycle efficiency must be devised.

The Carnot cycle efficiency is:

$$\eta = \frac{T_1 - T_2}{T_1} \qquad (1)$$

As can be seen from equation (1), the efficiency can be improved by increasing T_1 the absolute temperature at which heat is received or by decreasing the absolute temperature T_2 at which heat is rejected. For marine applications, T_2 is fixed or at least is not under the control of the system designer since the ocean provides the heat sink. Since T_2 cannot be reduced improvement in Carnot efficiency must come from an increase in T_1. Thermionic and magnetohydrodynamics processes employ temperatures greatly in excess of steam turbines or internal combustion engines and thus effectively raise T_1.

Another approach to improving efficiency would be to reduce mechanical losses. Thermoelectric and thermionic generation in which the actual conversion of heat energy into electrical energy is achieved with no moving parts offer some promise of improvement.

If the conversion of the energy stored in a fuel can be achieved directly without going through the intermediate conversion to heat energy then Carnot cycle limitations would not be a factor. The fuel cell operates in this manner.

In the succeeding sections some of these schemes will be examined with an eye to possible marine application.

THERMIONIC CONVERTERS

The first "exotic" scheme to be considered is the thermionic converter which, as will be seen is a static heat engine. The advantages of no mechanical losses are immediately achieved as are high operating temperatures with the apparent possibility of obtaining improved Carnot efficiency.

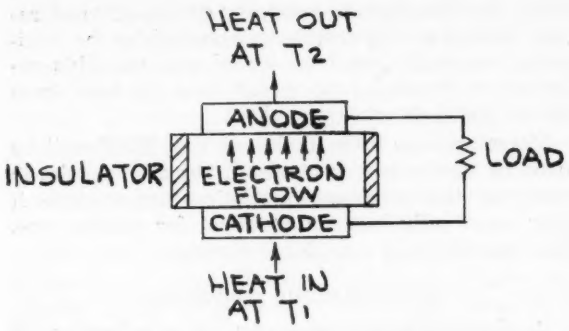
It has long been known that sufficiently high temperatures will cause emission of electrons from the surface of a heated solid. The principle has been used for many years in electronic tubes, but not as a basic method of generating electricity. As long ago as 1915, Schlichter proposed that thermionic emission might be used for power production. In the twenties, Charlton and Langmuir studied cesium filled diodes for such a purpose. Until very recently however, very little effort had been concentrated on the very formidable problems involved. Research in this area is now being pursued by, among others, Westinghouse, General Electric, R. C. A., Massachusetts Institute of Technology and Thermo-Electron Engineering Corporation. Some measure of success has been achieved.

The operation of the thermionic converter can be rather simply explained. The schematic diagram of such a device is shown in Figure 1(a). The cathode is heated and electrons are "boiled off" into an evacuated space. The anode, which is cooled, attracts the electrons which then flow from the anode through the load and back to the cathode.

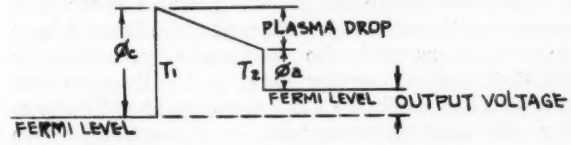
As heat is applied to the cathode, the electrons at the cathode surface are raised to a potential level greater than the work function ϕ_c of the cathode. Once the work function of the cathode is exceeded, electrons are driven off into the space between the anode and cathode. When an electron strikes the anode, it must surrender a potential equal to the work function of the anode ϕ_a. The energy level involved is illustrated in 1(b). It may be noted that the output voltage available is equal to the difference in Fermi levels between the anode and cathode.

In a high vacuum diode the electrons driven off

* The best diesel engines (with fuel rates as low as 0.315 lbs/SHP-hr reported) are exceptions to the above generalization.



(a) Schematic Diagram of Thermionic Inverter.



(b) Work Functions and Potentials of An Idealized Thermionic Inverter.

Figure 1

from the cathode must possess sufficient energy to overcome the space charge which will be built up in the diode. This is not indicated in Figure 1(b). In order to minimize the effects of this space charge, the spacing between the cathode and the anode must be kept extremely small. This spacing should not exceed a few mils and preferably should be one mil or less. This points out two difficulties. (1) Maintaining such close tolerances in any but small devices would be extremely difficult. (2) Since the thermionic converter is a heat engine, the difficulty of maintaining the necessary temperature differential between the cathode (heat source) and anode (heat sink) is extremely difficult with such close spacing.

The space charge problem can be overcome by filling the space between the anode and cathode with enough slow moving positive ions to neutralize the field created by the electrons. This is currently being done in most thermionic converter work by introducing a gas such as cesium into the cathode-anode gap. The cesium ions create a positive charged plasma which neutralizes the space charge built up by the electrons. One positively charged cesium ion effectively neutralizes the space charge of several hundred electrons.

Even with a cesium plasma, cathode-anode spacing unfortunately, must still be extremely small.

The output of a single thermionic converter is at a relatively low voltage of approximately one to two and a half volts. In order to obtain higher voltages, the cathode temperature must be extremely high. Efficiencies are, of course, strongly effected by the cathode temperature also. To obtain efficiencies which would be attractive, cathode temperatures of the order of 2000 to 2500 degrees Kelvin must be obtained.

At the present time, thermionic efficiencies in the 20 per cent range have been achieved. Theoretically, efficiencies of 50 to 60 per cent are possible but a realistic practical goal might be 40 per cent thermal efficiency.

To achieve efficiencies at this level requires development of materials able to withstand the high temperatures involved and a source of heat capable of providing the necessary temperatures. The material must be highly refractory and in order to achieve long life must have a low evaporation rate. To be useful they must have also a high electron emitting capacity. Research in this largely unexplored materials area should provide the necessary refractories. A nuclear reactor could provide the high temperatures required.

The formidable problems yet to be solved make it highly unlikely that thermionic generation will be part of any marine unit for many years, if ever. One ray of hope is that high efficiencies of the thermionic device alone is not necessary. With the high temperatures theoretically available from a nuclear reactor the thermionic unit could be used as a "topping device." The "waste heat" from the thermionic converter could be used as the heat source for a conventional steam plant. A calculated example [3] of just such a scheme assumed a nuclear steam plant having 27 per cent efficiency. A thermionic topping unit of 20 per cent conversion efficiency was added. The resultant overall efficiency was raised to 42 per cent!

MAGNETOHYDRODYNAMICS

Magnetohydrodynamics refers to the use of a gas passing through a magnetic field to generate an electric current. In a magnetohydrodynamics (MHD) generator, thermal energy is directly converted to electrical energy.

The MHD generator utilizes the Faraday principle of a moving conductor in a magnetic field and in this respect does not differ from a conventional generator. The differences arise in what kind of conductor is used and what kind of energy is being converted. In a conventional generator copper conductors are utilized. In a MHD generator a conducting compressible fluid (plasma) is used. In a conventional generator the mechanical energy provided by a mechanical heat engine forces the conductor through the magnetic field. In the MHD generator, no mechanical source is required. Figure 2 may be used for a simple explanation of the theory of the MHD generator. An ionized gas flows through a magnetic field in a channel (in the sketch the direction would be into the paper) and has an emf induced in it. Electrodes are inserted in the gas stream acting much like brushes in a direct current generator to pick up current from the electromotive force generated. This current then passes

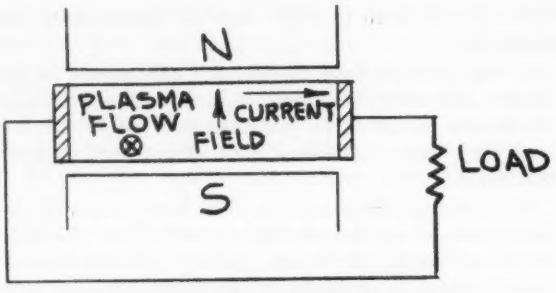


Figure 2. Schematic of MHD Generator.

through the load in a conventional manner and back into the plasma.

The preceeding explanation while simple in principle, describes a process which is somewhat more complicated. A high intensity heat source must be used to raise the temperature of a gas sufficiently high to ionize it so that it is a conductor and to impart enthalpy to the gas. This increase in energy level or enthalpy as well as increasing the temperature raises the pressure of the gas. The increased pressure provides the force to move the conducting gas (plasma) through the magnetic field where electricity is generated at the expense of a decrease in enthalpy of the gas. Similar to gas and steam turbines, the gas will leave the generator at a lower temperature and pressure than that which it had upon entrance but to be effective the exit temperature must remain above the level required to maintain ionization or conductivity.

If air is used as the conducting fluid it must be heated to approximately 6740°F to ionize it sufficiently to make it conductive. Seeding methods whereby alkali metal vapors are added to the air may reduce this temperature to approximately 4000°F. To obtain temperatures at this level with fossil fuels requires preheating the air to 2000°F prior to combustion or the use of pure oxygen instead of air.

The MHD generator is mechanically simple with no moving parts. However, just as with the thermionic converter the material problems are tremendous. The channel through which the plasma must flow must be able to withstand extreme temperatures without excessive vaporization and in addition must be able to withstand the erosion which is probable with gas velocities in the neighborhood of 2000 miles per hour.

Operating at these high temperatures provides a very attractive Carnot cycle efficiency. Actual thermal efficiency in the 55-60 range have been predicted but only in very high power ranges. Efficiency increases with size and MHD apparently will find its greatest potential in power plants of 100 megowatts or greater, well in excess of most marine requirements.

As with thermionic emission, MHD will most likely find its place as a topping device. It must reject heat at a temperature established by the minimum acceptable conductivity of the gas. This rejected or "waste" heat would then be used in a conventional steam cycle plant.

There appears little likelihood that MHD will be used in marine power plants. If research results in lowering the necessary ionization temperature it may eventually become practical for marine use. This possibility is considered remote.

THERMOELECTRIC CONVERSION

A thermoelectric generator is a collection of thermocouples suitably connected receiving heat at a high temperature and rejecting it at a lower temperature. As such, it is a Carnot cycle limited heat engine but as with the thermionic converters or MHD it has no moving parts and suffers no mechanical losses. Figure 3 is a simple schematic showing only one thermocouple. In a practical device there will be many pieces of p- and n- type semiconductor materials connected in series electrically with the junctions of one kind at a higher temperature than those of the other kind.

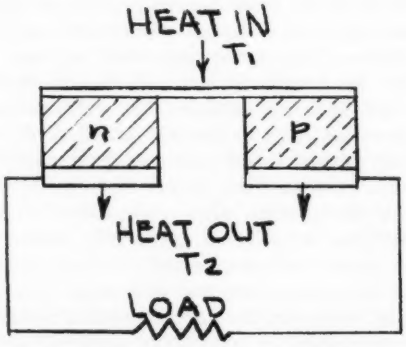


Figure 3. Schematic of Thermoelectric Generator.

Almost 150 years ago, Thomas Seebeck noted the phenomenon on which thermoelectricity is based. Because of lack of knowledge of materials and reduced incentive caused by development of heat engines little work was done in the field until very recently. Practical use was limited to the familiar thermocouple measuring devices.

The tremendous advances in basic solid state physics since World War II and the technological improvements in semiconductor material manufacturing and fabrication provided startling improvement in thermoelectric generation potentiality in recent years. Efficiencies improved from negligible amounts by orders of magnitude. These gains gave rise to considerable optimism that further dramatic gains were just over the horizon and that thermoelectric generation could be a serious competitor in the generation of power. The possibility of in-

stalling thermoelectric elements directly "in pile" in a nuclear reactor is extremely attractive. The complexities of primary coolant-secondary coolant loops, pumps, heat exchangers and so on would be largely eliminated. Heat would be supplied at the hot junction by the fission process and sea water would provide the coolant or heat sink. Alternatively, fossil fuels could be used in the same manner.

Since the first early successes, progress has been disheartingly slow. Thermal efficiencies have improved to the neighborhood of five per cent. This, contrasted with the 40 per cent of a fossil plant or the 28 per cent of a nuclear plant in shore practice, shows that several fold improvement is necessary before thermoelectric generation for large power production can be practical. In certain specialized applications such as SNAP (space nuclear auxiliary power) or similar schemes for lighted buoys the low efficiency is of secondary importance. In such applications, thermoelectric generation can find a place. To reach efficiencies that will be attractive for powering ships, new materials will have to be discovered. What these materials may be is not known and indeed they may not even exist.

FUEL CELLS

The three schemes examined so far have a commonality in that they are all heat engines, although static, and are thus Carnot cycle efficiency limited. The fuel cell does not rely on temperature differentials between heat sources and sinks but is entirely different in concept.

The fuel cell is an electrochemical device for directly converting chemical energy into electrical energy. The intermediate step of conversion to heat energy is avoided. The common flashlight battery is also an electrochemical device which converts chemical energy into electrical energy. The fuel cell and the flashlight battery are both primary batteries —but with a difference. In the flashlight battery the fuel and oxidant that combine to provide the electrical energy are sealed in the battery case. When they are totally combined the cell is thrown away and a new one purchased. In the fuel cell the fuel and oxidant are stored external to the cell and fed to it continuously and at a rate determined by the electric load. Waste products are continuously removed. The fuel cell, for this reason, is often termed a "continuous feed primary battery."

In a heat engine utilizing fossil fuels, the *heat of reaction* when the fuel combines with an oxidant provides the heat source. With present engines a large proportion of the heat thus generated is rejected to a heat sink. In a fuel cell when the fuel combines with an oxidant there is a *free energy change* with ideally all the free energy change becoming available as electrical energy. None of it need be rejected in order to make the reaction go. Without considering the difference between heat of reaction and free energy change except to state that it often is of negligible consequence, the practical advantage of a fuel cell over a heat engine is immediately apparent. If both were using the same type and amount of fuel, substantially greater energy output from the fuel cell could be expected than from a process involving conversion from thermal to mechanical or electrical energy.

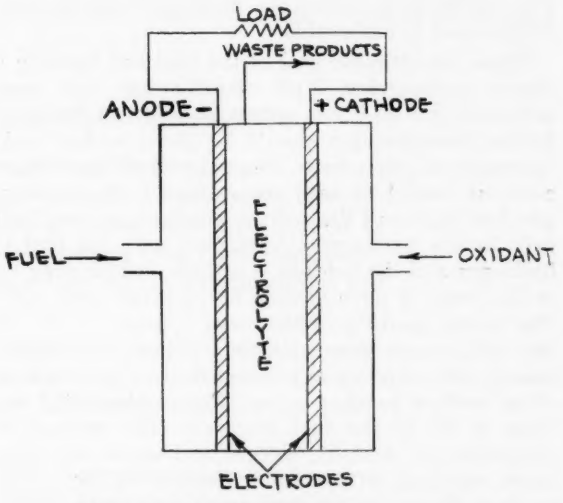


Figure 4. Schematic Diagram of a Fuel Cell.

The essential parts of a fuel cell are shown schematically in figure 4. They are a fuel electrode, an oxidant electrode and an electrolyte. The fuel may be hydrogen, alcohol, hydrocarbons, metals or any other oxidizable substance. The oxidant may be oxygen, air, peroxides, chlorine, fluorine or any one of a wide variety of other agents. Electrodes have been constructed from carbon and from metals. The electrolyte may be aqueous, liquid molten salts, molten salts in a ceramic matrix or acidic as in an ion-exchange membrane. Operation may be at high or low temperature and at high or low pressure. The possible combinations of substances and operating conditions are myriad.

Dr. J. B. Friauf in [5] has described the type of cell desired for U. S. Navy applications as:

"A fuel cell which would burn a cheap hydrocarbon fuel directly in the fuel cell, using air as an oxidant when air is available, and oxygen, or an even better oxidant if one can be found, when air is not available; would do this at about room temperature and pressure; and would also be of reasonable size, weight, and cost, and of high reliability and long life."

Such a cell is not available at this time. Cells burning hydrocarbons directly have been devised but none of them have come close enough to the foregoing criteria to be practical in the immediate future. The degree of success achieved however, is

such as to suggest that they may someday be a reality. One of the largest, if not the largest, unsponsored research efforts in the country today is directed toward achieving an economically attractive fuel cell. Success could have a terrific impact on the nation's economy. There is considerable government sponsored research aimed at specific applications also being carried on. While these do not insure success, the magnitude of effort indicates that there is considerable informed opinion that such a goal is achievable.

Since the ultimate goal of the fuel cell burning a cheap hydrocarbon fuel directly has not been achieved and does not appear possible in the near future, consideration should be given to fuel cells operating on other fuels. The cells which have been most successful to date are various hydrogen-oxygen fuel cells and the sodium-amalgam-oxygen fuel cell. In the hydrogen-oxygen fuel cell, the fuel is hydrogen and the oxidant is oxygen (which may be in the form of pure oxygen or obtained from air). The waste product in this case is pure water. In the sodium-amalgam fuel cell, sodium is amalgamated with mercury to prevent the violent reaction when sodium touches water. The amalgamated sodium is fed to the fuel electrode. The oxidant is oxygen or air. Sodium, oxygen and water are combined resulting in sodium hydroxide as the waste product. Since sodium hydroxide is also the electrolyte in this cell, removal is simply accomplished by draining off electrolyte and adding sea water to make up for the water which is lost.

The sodium-amalgam fuel cell uses a rather expensive fuel. Also, considerable caution must be exercised in the handling of sodium. Since amalgamated sodium is a good electrical conductor, special means must be used to prevent short circuiting cells connected in series. (This latter problem has been solved by the M. W. Kellogg Co.) There are some off-setting advantages of this cell to go along with the disadvantages previously mentioned. The cell works well electrochemically and individual cell voltage is approximately twice that of the hydrogen-oxygen fuel cell. Practically, this means that fewer cells need be connected in series for a given output voltage. Also, the disposal of waste products as previously mentioned, is very simple. The cell should have extremely long life since there is nothing inherent in the cell or electrode construction which should limit life.

There are some problems with the hydrogen-oxygen fuel cell also. These are:

1. It requires hydrogen as a fuel. The storage of large amounts of hydrogen on board ship is highly undesirable.

2. In most cells, there is a problem of dilution of the electrolyte by the product water requiring either electrolyte make-up or some recirculation scheme to get the water out of the electrolyte.

3. To date, all reported hydrogen-oxygen fuel cells have a life which is unacceptably short for most applications.

The first problem may be solved by generating hydrogen on board from some other fuel. Hydrogen can be produced in a good many different ways. It may be simply produced from such materials as metal hydrides but this would be prohibitively expensive for most uses. Fortunately, hydrogen can also be generated from various hydrocarbon fuels, methyl alcohol and ammonia. In the case of the hydrocarbons and methyl alcohol, it can be accomplished by steam reforming. In the case of ammonia, hydrogen may be generated by thermal decomposition. These reactions are generally endothermic and therefore, require the addition of energy. Practically, this means that part of the fuel carried must be burned in the hydrogen generator in order to obtain hydrogen for the fuel cell. This is not necessarily an extremely wasteful process. For example, in the reforming of methanol, it is theoretically possible to obtain sufficient hydrogen to provide in excess of 90 per cent of the thermal energy originally available in the total methanol used. Production of hydrogen from hydrocarbons is now being accomplished commercially at about 65 per cent efficiency on the basis of energy available originally to that available in the hydrogen produced.

Fuel cells theoretically can approach 100 per cent efficiency based on free energy change. Actual efficiencies of the order of 70 per cent are being achieved. Starting with a hydrocarbon fuel, such as diesel oil, and reforming it to produce hydrogen, it is now possible to obtain an overall pounds of fuel per shaft horsepower hour intermediate between marine steam and diesel plants. Theoretical calculations using JP-4 (naptha) indicate the possibility of bettering considerably the best diesel fuel rate if this fuel is used to produce hydrogen. Direct conversion of the fuel, when achieved, should give efficiencies in the 70 per cent range.

While the efficiency of the hydrogen generation-fuel cell combination would be attractive for some purposes now, improvement in life is necessary before it could be considered a real competitor in the marine field. Specialized applications might accept life in the order of thousands of hours. But to be truly competitive, life in the tens or hundreds of thousands of hours of operation appear mandatory.

SUMMARY

Problems associated with thermionic, magnetohydrodynamics and thermoelectric power generation are mainly in the materials field. Although the problems may be solved, these systems do not appear to be prospects for marine propulsion for many years to come. Problems with the fuel cell appear much less difficult of solution. Based on the state-of-the-art of the fuel cell, it appears probable that they will be real competitors in power production within the next decade.

The problems of space, weight and costs of all of these systems have been avoided in this paper. While informed estimates might be made at this time, they would be only estimates and of dubious validity.

REFERENCES

[1] R. W. Porter, "Adventures in Energy Conversion," *Electrical Engineering,* October 1960.

[2] Eric Randall, "Unconventional Power Sources," *Electrotechnology,* September 1961.

[3] "Future Power Generation," Transcript of Proceedings of meeting held by Westinghouse Electric Corporation for executives of Electric Utility Industry, March 1960.

[4] "Fuel Cells," Prepared by students of Graduate School of Harvard University, published by the Purnell Co., October, 1960.

[5] J. B. Friauf, "Fuel Cells—The State of the Art and the Navy Program," talk delivered at Navy Research and Development Clinic held at Raton, New Mexico, 28-29 September 1961.

[6] C. F. Viglotti, "Hydrogen Generation From Methyl Alcohol and Ammonia," private communication dated 15 September 1961.

ZIRCALOY-2 PRODUCED BY POWDER METALLURGY

Zircaloy-2, produced by a unique powder-metallurgy process, is commercially available from the Metallurgical Products Department, Detroit, Mich., of General Electric. A modified hot-pressing technique is used to produce finished or semifinished shapes requiring only light machining. The process can also be used for such refractory metals as columbium and tantalum.

Even special shapes can be held to close tolerances to eliminate the cost of machining and the loss of valuable material. For extruded tubing, a hole can be formed directly in a Zircaloy-2 billet without drilling or piercing.

Zircaloy-2, a zirconium-base alloy, offers the nuclear industry low neutron cross section, good mechanical strength, heat resistance, and excellent corrosion resistance to high-temperature steam.

For chemical applications at room temperature it resists attack by most organic acids, all concentrations of nitric, some concentrations of sulfuric, and in general hydrochloric and other chlorides. Alkaline-solution attack is resisted and it also has a high resistance to violently corrosive materials.

Outstanding physical characteristics are those normally associated with a wrought product. For instance, the density of 6.57 grams per cc, which is 100 per cent of theoretical. There is freedom from porosity and properties are nondirectional.

Mechanical Engineering, August 1961

SAFETY FIRST!

Any apparatus that develops THRUST is ONLY as safe and dependable as the BEARING which transmits the thrust from the moving to the stationary parts.

KINGSBURY THRUST BEARINGS, embodying the original concept of the **pivoted shoe** and the **self-renewing oil film,** offer the maximum in safety and dependability for any type of application.

THEY ARE BACKED BY 50 YEARS OF EXPERIENCE & KNOW-HOW

SPECIFY KINGSBURY!

Kingsbury Machine Works, Inc. KINGSBURY **Frankford, Philadelphia 24, Pa.**

Bath Iron Works

General view of Bath Iron Works plant about 1957.

JOHN R. NEWELL

THE BATH IRON WORKS

THE AUTHOR

is President of the Bath Iron Works Corporation. He has held this position since 1950 when he succeeded his father, William S. ("Pete") Newell. Mr. Newell received his education at Philips Andover Academy and the Massachusetts Institute of Technology from which latter he received the Bachelor of Science degree in 1935. Upon graduation he joined the Shipbuilding Division of Bethlehem Steel Co. at Quincy as a testing engineer. In 1938 he became assistant to the General Superintendent of Bath Iron Works. He has been with Bath ever since except for a tour in the Navy (1944-1947) as a Lieutenant, USNR. Mr. Newell is president of the Society of Naval Architects and Marine Engineers, having been elected to that office for a term of two years in November 1960.

General view of Bath Iron Works plant about 1957.

THE GREAT American industry of shipbuilding was born at the mouth of the Kennebec River in Maine, 12 miles from Bath, 354 years ago. There, in the awesome stillness of the lonely Maine coast and the trackless wilderness, the pinnace *Virginia of Sagadahoc* was built in 1607 by the Popham colonists. Fashioned of native oak and pine, she became the first American vessel to engage in overseas commerce. It was in the historical wake of a strong and able ship—the *Virginia* (built in Maine!)—that the American Merchant Marine was later developed.

In this development no river and no port played more prominent roles than the Kennebec and Bath in the days of sail. In the capable hands of succeeding generations of shipbuilders, the standards of quality and seaworthiness set by the colonists in 1607 have been conscientiously carried on for over three and a half centuries.

As it did in the era of sail, the great heritage lives on in the era of steam. It will live in the dawning era of nuclear power. This legacy is timeless, destined to serve America as long as men sail the deep waters.

As the sole surviving shipyard of scores which once lined the Kennebec River, the Bath Iron Works Corporation is keenly aware of this heritage of fine craftsmanship established and maintained for so many years on these shores. Since Sir George Popham built the *Virginia,* over four thousand ocean going ships of wood, iron and steel have been launched from the Kennebec's shipyards.

In 1826 the Bath Iron Works started as a small

Bath Iron Works

The first Bath built ship. Pinnace *Virginia Of Sagadahoc*, built in 1607. Photo of model.

foundry. It was succeeded in 1884 by the Bath Iron Works, Ltd. General Thomas W. Hyde, first president and principal owner of Bath Iron Works added the manufacture of equipment and machinery for ships to the foundry business. The company's first shipbuilding contract, received in 1889, was for the construction of the wooden steamer *Cottage City*, which operated in the passenger and freight business between Portland, Maine and New York City.

In 1890 contracts were obtained from the United States Navy for construction of the steel gunboats *Machias* and *Castine*. These ships were the first of a long line of Naval vessels—a battleship, cruisers, torpedo boats, destroyers, destroyer leaders, frigates . . . to be built by the Bath Iron Works.

During the decade from 1890 to 1900 the company built thirty vessels, including the passenger steamer *City of Lowell;* the *Aphrodite,* the largest and fastest steam yacht ever built in this country up to that time; the first composite, electrically lighted lightship; the *Winifred,* the first ocean-going American tramp steamer; and the *Dahlgren* and *Craven,* the fastest torpedo boats in the Navy up to that time.

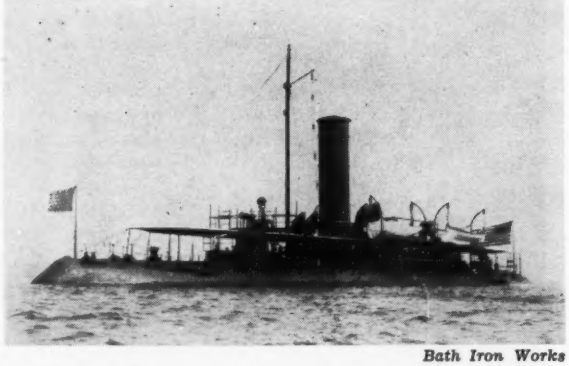
The Bath Iron Works was most fortunate in obtaining, from the beginning, some excellent technical men, such as Charles E. Hyde, a brilliant marine engineer and a cousin of General Hyde, who designed and built the first triple-expansion engine in America. Scotch and English workmen from the Clyde formed a nucleus of skilled labor and taught Bath's builders of wooden ships the new techniques of iron and steel shipbuilding and steam propulsion when the wooden sailing ships were on the way out. Early in the 20th century such outstanding men as Charles P. Wetherbee and John McInnes added to Bath's reputation for outstanding ships.

About the turn of the century, the Bath Iron Works launched the torpedo boat destroyers *Bagley, Barney* and *Biddle*. These small (157′-0″), fast boats, with plating ⅛″ thick, were the last torpedo boats to be authorized by the Navy until the day of the PT boats of World War II.

In 1906 the Battleship *Georgia* (BB15) was delivered to the United States Navy, in that day the fastest and one of the most powerful battleships afloat.

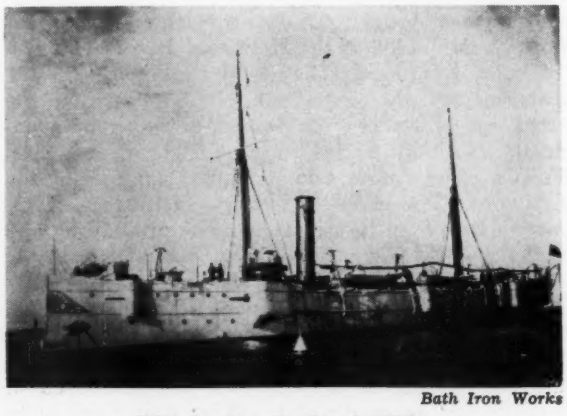
The years from 1910 to 1920 saw the change from coal-fired to oil-fired boilers for turbine driven destroyers and the building of the destroyer *Wadsworth,* the first geared turbine vessel in the U. S. Navy. The Bath Iron Works designed and built many of the famous four-pipers during World War I, seven of which were transferred to Great Britain in the darkest hours of World War II and helped materially in saving England's merchant fleet from destruction by German submarines.

Prior to 1917 the company had been owned and controlled by various members of the Hyde family,



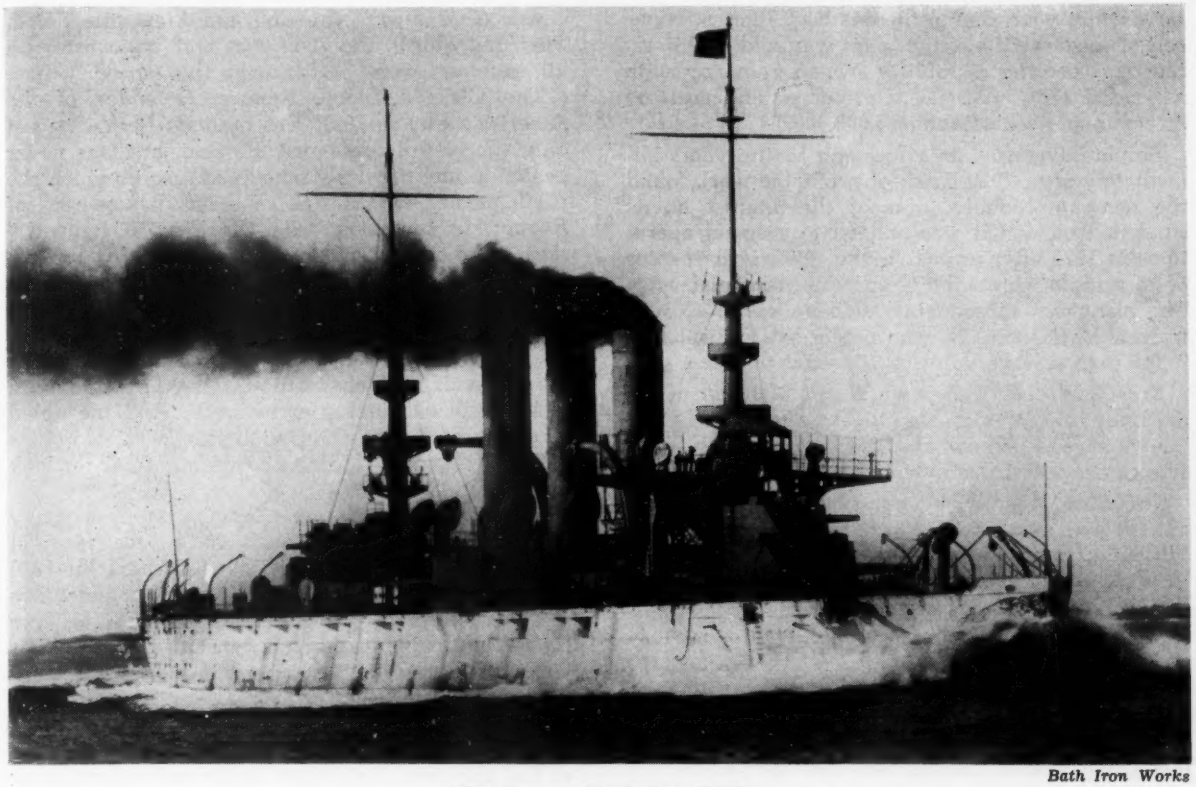
Bath Iron Works

USS *Katahdin*, Armored ram, built by Bath in 1895.



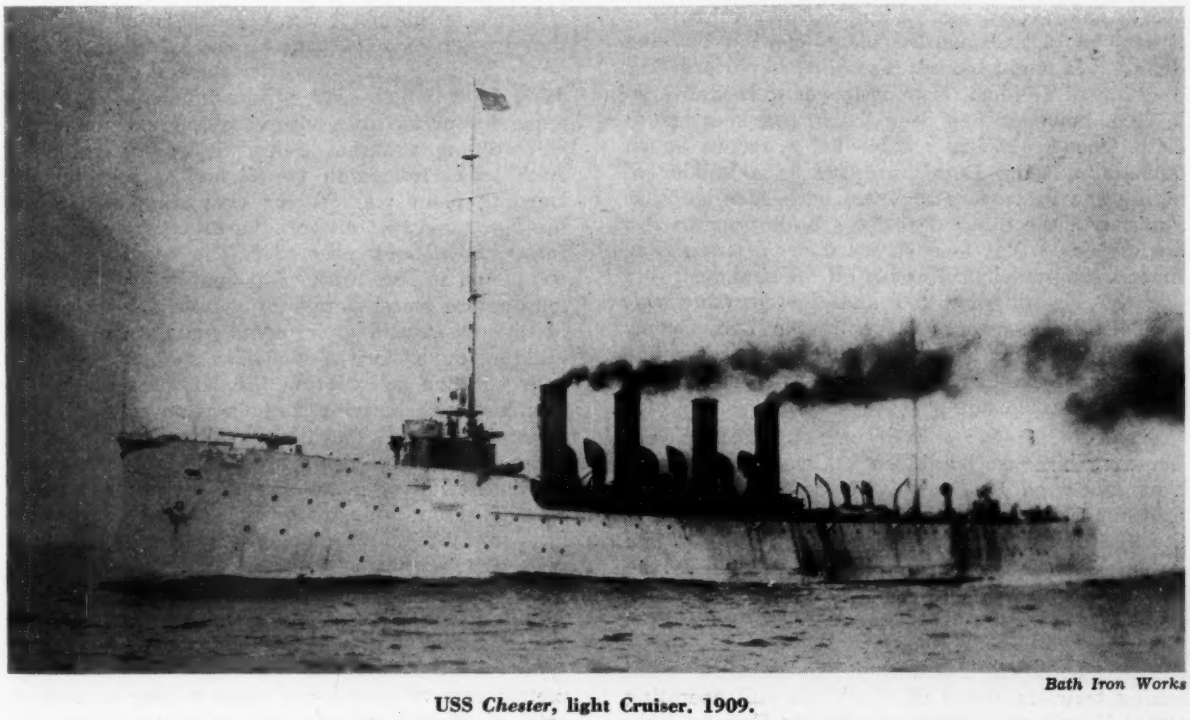
Bath Iron Works

USS *Castine*, Gunboat. 1890.



Bath Iron Works

USS *Georgia*, Battleship. 1906.



Bath Iron Works

USS *Chester*, light Cruiser. 1909.

but in that year, due to the death of John S. Hyde, son of General Hyde, the plant was sold by his estate and became a publicly owned company with a bonded debt, an issue of preferred and an issue of common stock totaling $3,000,000.

Shipbuilding was at a low ebb in the years immediately after 1920. Lack of profitable work found the company unable to meet the interest on its funded debt, and it was obliged to suspend operations in 1925 after an active and noteworthy career of 35 years of shipbuilding and marine engineering. The plant was subsequently sold under foreclosure to New York interests, who proceeded to dismantle it for such salvage value as it would produce.

In 1927 William S. Newell, Works Manager of the old Bath Irons Works, Ltd., together with Archibald M. Main reopened the Bath yard as the Bath Iron Works Corporation.

The Bath Iron Works was re-equipped, to some extent, with machinery purchased from the famous William Cramp & Sons Shipyard of Philadelphia, then in liquidation.

Bath's first contract under "Pete" Newell's management was for a 240 foot yacht, the *Vanda*. This was followed by numerous other large yachts, including the *Corsair* for J. P. Morgan and the *Aras*, later the Presidential yacht, *Williamsburg*, and several trawlers for the Boston fishing fleet. Seven 165 foot Coast Guard Cutters followed the yachts.

In 1931 Bath submitted a bid for the first destroyer to be built by the Navy since World War I. About this time rumors spread that the Bath Iron Works had no business bidding on Navy work, since it was an old, dismantled plant, cleaned out and done for. It might bid but it's ability to perform was questioned. The last Navy destroyer to be delivered in 1921, however, had been the *Pruitt*, launched at Bath. The *Pruitt* had established a record as an outstanding ship. Bath's prestige as a builder of high grade destroyers survived with such ships as *Pruitt* and the other destroyers built prior to and during World War I—even when her financial fortunes were very low. Her bid on the new destroyer was the lowest submitted and the company was awarded the contract. The ship, the USS *Dewey* (DD349) was completed on schedule and her fine performance reaffirmed the Bath tradition for excellent workmanship.

The contract for the destroyers *Drayton* and *Lamson*, designed by Gibbs & Cox, Inc., of New York, followed the *Dewey*. These ships were the forerunners of the destroyer designs culminating in the 2100 and 2200 tonners which later fought the battles of World War II in the far reaches of the Pacific, off the beaches of Normandy and Casablanca and in the stormy waters of the North Atlantic.

Throughout the 1930's Bath continued to build fishing trawlers, many of which are still operating out of New England ports; the *Boston College, Holy Cross, Georgetown,* the *Ebb and Flow,* the *Swell, Surf and Storm,* the *Arlington* and *Winchester;* in all, eighteen were built during this period.

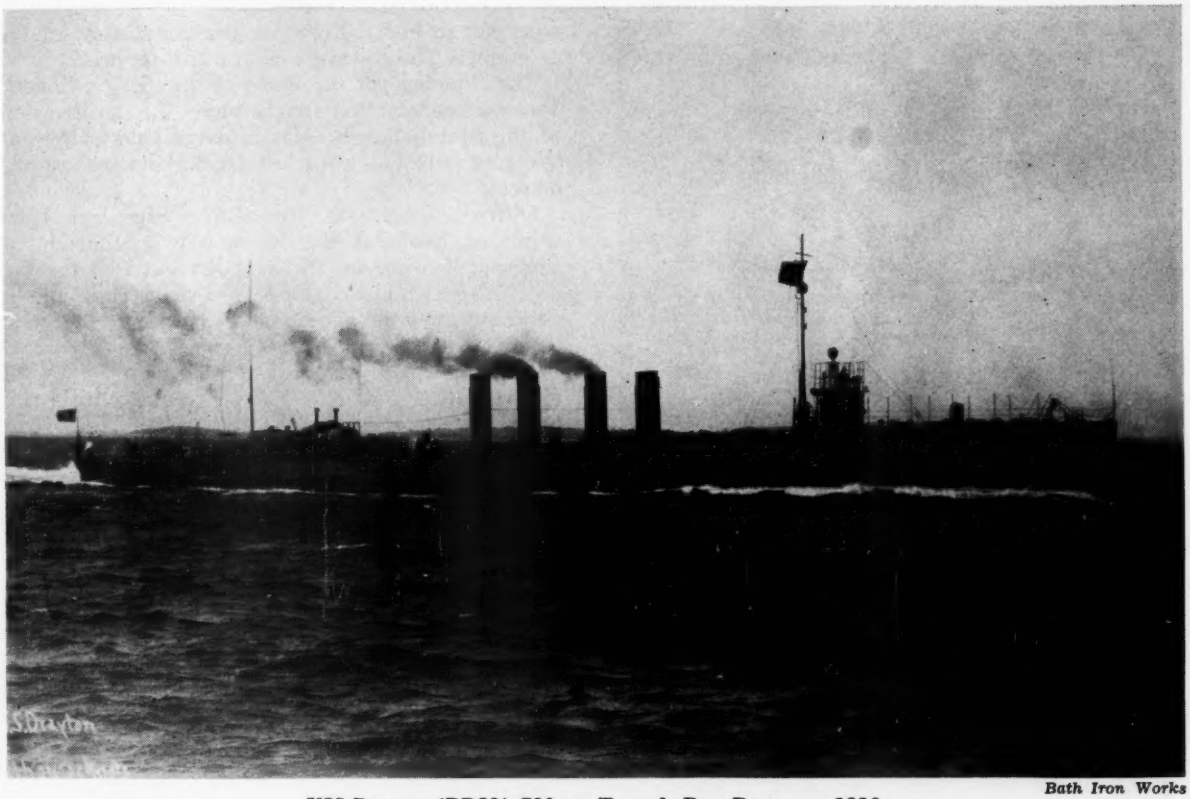
The Class J Sloop, *Ranger,* Defender of the America's Cup in 1937, was built by Bath. She not only successfully defended the Cup, but was never beaten in any regularly scheduled race in which she participated. Harold S. Vanderbilt, owner of *Ranger,* in his book, "On the Wind's Highway," says, "The officers and employees of the Bath Iron Works deserve no small measure of whatever credit may be due for the *Ranger's* success. Mr. Newell's sporting cost-basis offer (of construction) was the deciding factor in my decision to proceed single-handed with her construction. I have never seen a vessel built as quickly or as well." And the noted yachtsman, Sherman Hoyt, says of her in his "Memoirs"—"Take her all in all, we shall not look upon her like again!"

In 1936 Bath became a publicly owned company with 395,000 shares outstanding. Its stock was at first listed on the old Curb Exchange but in 1940 was listed on the New York Stock Exchange. The original issue was sold to the public for $12 per share. Stock dividends have increased the number of shares outstanding to approximately 420,000.

With the approach of World War II Bath built the Harding Plant on a 60-acre site 3½ miles from the main plant, because of limited room to expand at the shipyard. This plant embraced a fabricating shop, complete with mold loft, heavy metalworking machinery, bending floor and assembly areas, a galvanizing plant and a sizable warehouse. The construction of this plant was undertaken suddenly on the strength of a telegram received from Secretary of the Navy, Knox, soon after the fall of France in June 1940, which said, "Take immediate steps to expand your facilities with view to greatly enlarged shipbuilding program. Speed is of the essence." Bath took "immediate steps" and as a result the Harding plant was 70 per cent completed when the Navy contract authorizing its construction was received—in September 1940. The new facility was completed in December 1940 and in full operation long before many shipyards had turned a spadeful of dirt to expand their plants for the great shipbuilding expansion of 1940-42.

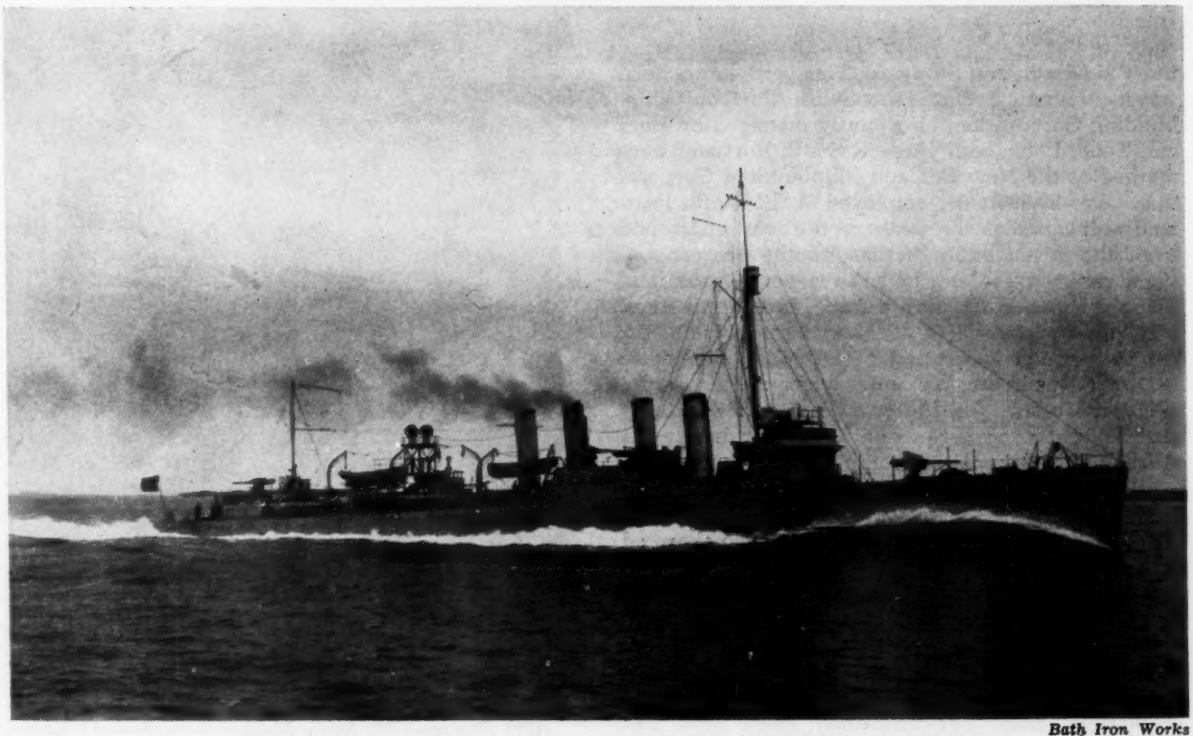
In addition to building the Harding Plant, the Company purchased a large portion of the Maine Central Railroad's freight yard adjoining the northern boundary of the shipyard in 1941. On this site it built a new double set of building ways, a large warehouse and an assembly shop and a new station for the railroad. The main fitting-out wharf was reconstructed and enlarged at the same time.

As a result of the rapid addition of new facilities, the yard was able to deliver the first 2100, the first 2200 and the first 2250-ton destroyers, the largest types built during World War II and reached a completion rate of twenty-one ships a year in 1943. A total of 86 such vessels was delivered during the



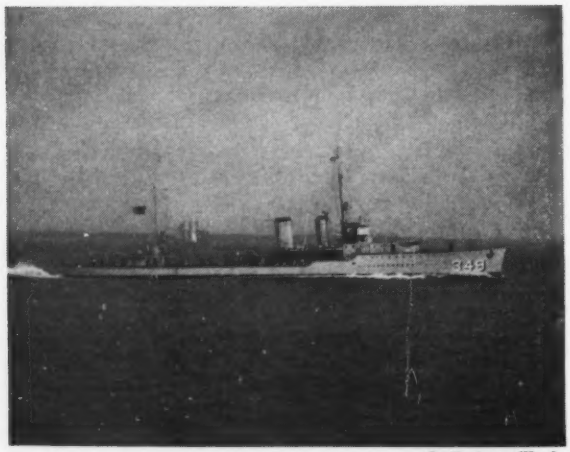
Bath Iron Works

USS *Drayton* (DD23) 700 ton Torpedo Boat Destroyer. 1910.



Bath Iron Works

USS *Pruitt* (DD 347). Last of the "four pipers," making 36.47 knots. 1920.



Bath Iron Works

USS *Dewey* (DD 349). The first post-W.W. I Destroyer.

war period, nearly one fourth of all the destroyers built in the United States. Employment reached 12,000 at the height of the program.

In 1940 Todd Shipyards Corporation and Bath Iron Works affiliated as the Todd-Bath Iron Shipbuilding Corporation to build 30 cargo ships for the British Purchasing Commission. These ships were built in a new basin type shipyard at South Portland, Maine. This was the first basin type shipyard built in the United States. Several yards have now adopted the basin technique for ship construction.

Within four months of the start of the Todd-Bath Iron basins, the Maritime Commission requested the company to build a second shipyard to the west of the Todd-Bath Iron Shipyard. This yard, an inclined ways shipyard, became the South Portland Shipbuilding Corporation, also jointly managed by Bath and Todd. Later both yards at South Portland were merged as the New England Shipbuilding Corporation. Over 30,000 were employed at the South Portland shipyards at the peak of the war effort and from the seven basin berths and the six conventional ways were launched the impressive total of 30 British Ocean Class ships and 244 Liberty ships.

The oldest destroyer in the Navy during World War II was the four-stacker *Allen* (DD66). Launched in 1917, she was in the front lines when the bombs fell at Pearl Harbor. The life of a destroyer is 16 to 20 years, but after a quarter of a century of service the *Allen* was still in there pitching. She continued in service throughout the war.

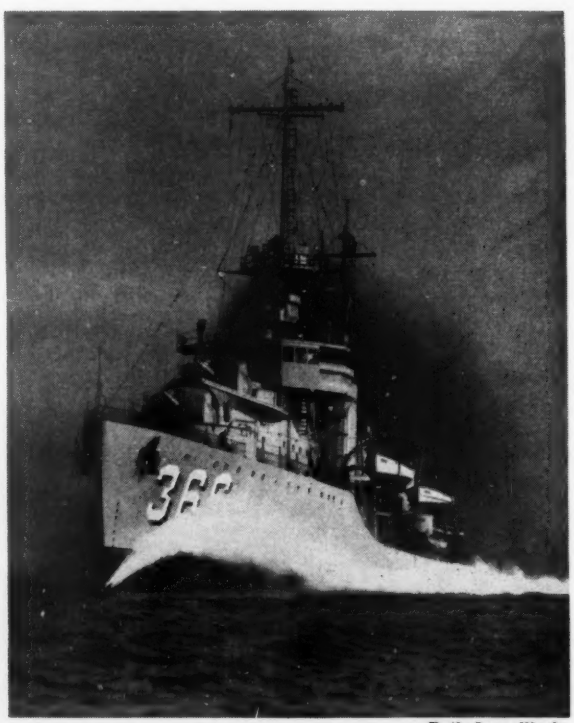
The Bath ships fought well during the War. Not all of the ships from the Kennebec led the charmed life of the *Sigourney*, which took part in most of the major Pacific operations, from the Solomons through the Philippines, including the fierce battle of Leyte Gulf and came through without a scratch. There was also the "Lucky *Ludlow*," and the Queen of the Tin Can Fleet, *O'Bannon*, which for all her brilliant encounters, came out unscathed, even from her close engagement with a Japanese battleship. Others were not so lucky. Eight sank under enemy bombs or gunfire. The *Spence* was lost in a typhoon.

The *Stembel* got the name of the "Black Sheep" because she so often fought alone. In the invasion of the Marshalls, she was a rendezvous ship—not the pleasantest of jobs. At Guam, she was traffic director.

O'Brien fought at Iwo Jima. She had been wounded badly at the Normandy beachhead but they patched her up and sent her out into the Pacific. The kamikazes ripped her open at Lingayen Gulf, but the crew jammed mattresses into the holes and kept going.

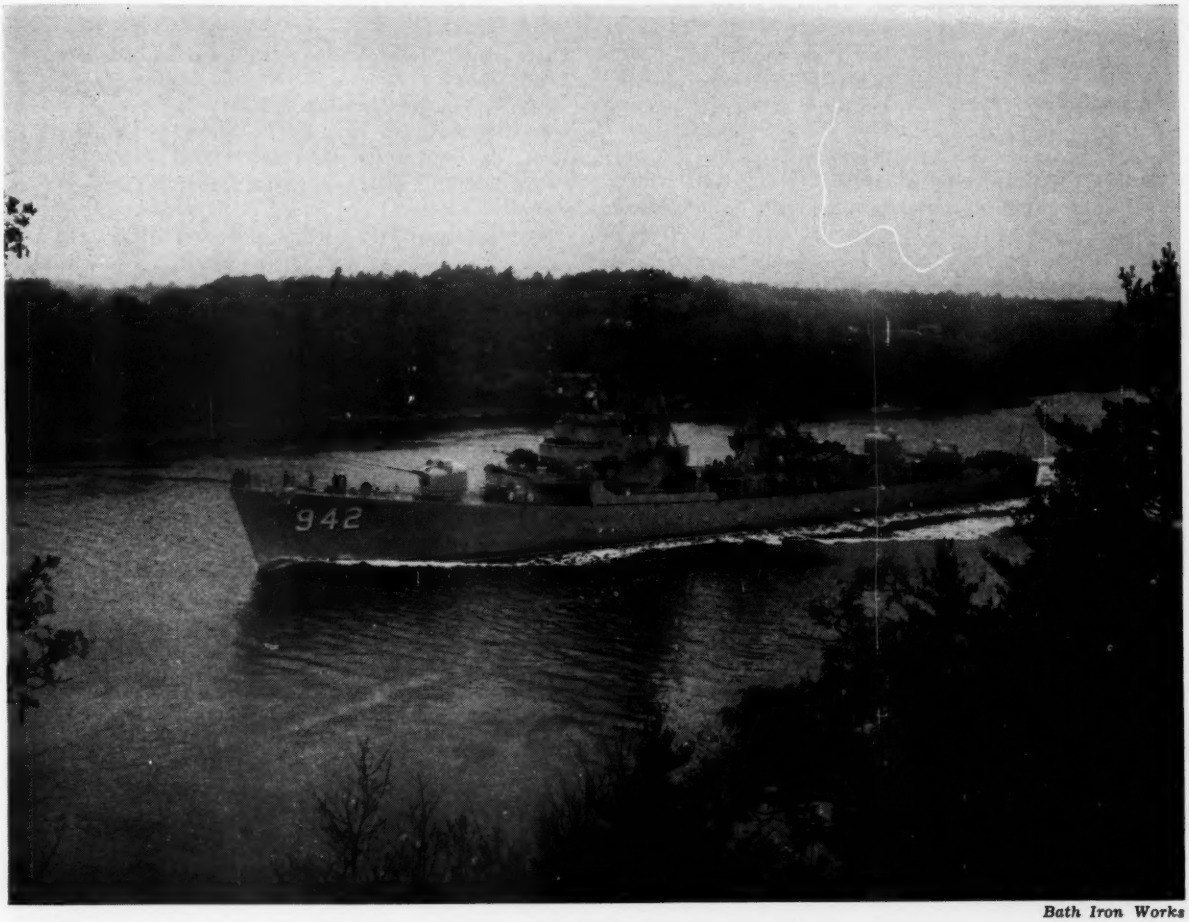
Another kamikaze-struck Bath ship was the *Hughes*. After long and brilliant war service a suicide plane crashed through her port side into the engine room and exploded. Groggy but not out, the *Hughes* kept going. She got patched up at Humboldt Bay, a little more at Pearl Harbor and complete repairs in San Francisco. Then she returned to Japan to help enforce the terms of surrender.

The *Wadleigh* got her baptism of fire attacking Ailinglapalap Island in the Marshalls. At Saipan she saw heavy action. Later in Kossol Passage she struck a mine, lost all power, got herself tied up to a floating drydock, escaped Jap bombs that dropped all around, rode out a typhoon and limped into Pearl Harbor for repairs and was patched up in time to steam into Tokyo Bay with our victorious fleet.



Bath Iron Works

USS *Drayton* (DD 366). Making more than 41 Knots! 1936.



Bath Iron Works

USS *Bigelow* (DD 942), one of the nine 2850 ton destroyers built by Bath between 1955 and 1958 steams down the Kennebec from Bath to Popham on the sea.

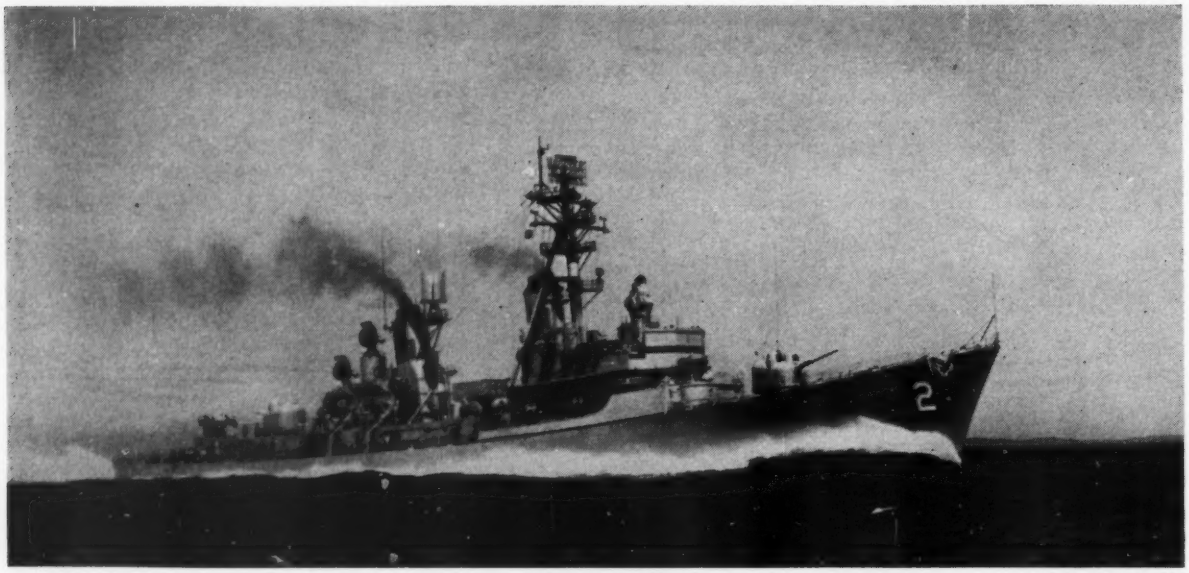
The *Nicholas, Chevalier, Strong, Taylor* and *De Haven*—the first of the 2100-tonners, fought for the most part in concert. With them would often be the *Aaron Ward, Barton* and *Laffey*. The *Strong* was torpedoed and sunk in the Kula Gulf, the *Chevalier* was split in half by a torpedo in the fierce action at Vella Lavella. The *Nicholas* operated in the Slot for many months, was in the covering force as our flag was returned to Luzon Island and helped in the recapture of Corregidor.

The *Laffey* survived what was probably the fiercest kamikaze assault ever made by the Japanese against a single warship. Off Okinawa in 1945 twenty-two kamikaze pilots attacked her. When it was over the *Laffey*, flame-blackened and riddled from stem to stern, went back to Seattle under her own power and was thrown open to public inspection as a dramatic demonstration of the ruggedness of destroyer construction.

And then suddenly the war was over. Naval shipbuilding was cut back drastically. To keep the Bath organization intact on a greatly reduced scale, a contract for thirty-two trawlers was taken from the French government, which resulted in a considerable loss. The Yacht *Haida* was launched in 1947. Soon thereafter naval construction picked up a little. Reconversion work on three naval attack cargo ships was followed by the completion of the hunter killer destroyer *Epperson* and the escort destroyer *Robert A. Owens*. To help stabilize activities, Bath purchased the Pennsylvania Crusher Company, for many years a leading producer of heavy crushing machinery, as one of several diversification ventures.

In 1947 the author became Vice President in charge of Production. In 1950 he succeeded his father as President, which position he still holds.

The experimental, advanced design, light weight destroyer *Timmerman* (DD828) was delivered in September 1952. The USS *Mitscher* and USS *John S. McCain* (DL2 and 3) were completed in 1953. These new design ships had a special job to do—to



Bath Iron Works

USS *Charles F. Adams* (DD 62).

Bath Iron Works

USS *Dewey* (DLG14).

The latest Bath built Naval types. 1960.

serve as a screen for fast carrier task forces. Big, seaworthy ships, they were equipped with all the latest devices for antisubmarine and antiaircraft warfare, but had greatly reduced weight power plants, although not as extreme as the *Timmerman*.

During the Korean war Bath built five new design Landing Ships, Tank (LST1156-60), followed by three new ocean escorts of the *Dealey* Class. In late 1952 Bath was low bidder on the first three ships of the *Forrest Sherman* Class, and later was awarded six more of this class. Bath built 9 of the 18 ships of this class.

In 1956 Bath was awarded a contract for the last two guided missile frigates of the DLG6 Class, USS *Dewey* (DLG14) and USS *Preble* (DLG15). These ships were completed 10 and 9 months respectively ahead of contract delivery date.

In 1957 Bath was awarded a contract for the first of the new guided missile destroyers carrying the Tartar weapon. Three of these ships have been completed. A fourth will be delivered in October 1961.

In late 1958 the first "double ended" Terrier missile frigates, (DLG16-18), were ordered from Bath. Three somewhat larger ships, 547 feet long, were contracted for in May 1961, to be delivered in 1965.

During the past ten years Bath Iron Works has greatly improved its facilities, having spent over $10,000,000 installing heavier cranes, improving and lengthening building ways, rebuilding piers, and in construction of a new structural assembly building, new electric shop and improved pipe shop facilities. Most machine tools have been replaced since the end of World War II.

Over the past seventy-odd years, Bath has been primarily a builder of fast, medium size vessels, with occasional construction of merchant ships, yachts, trawlers and coast guard vessels of various sorts. Bath has earned and steadfastly maintained a reputation for performance, both as to quality of workmanship and timeliness of completion, which is equalled by few other shipbuilders and exceeded by none.

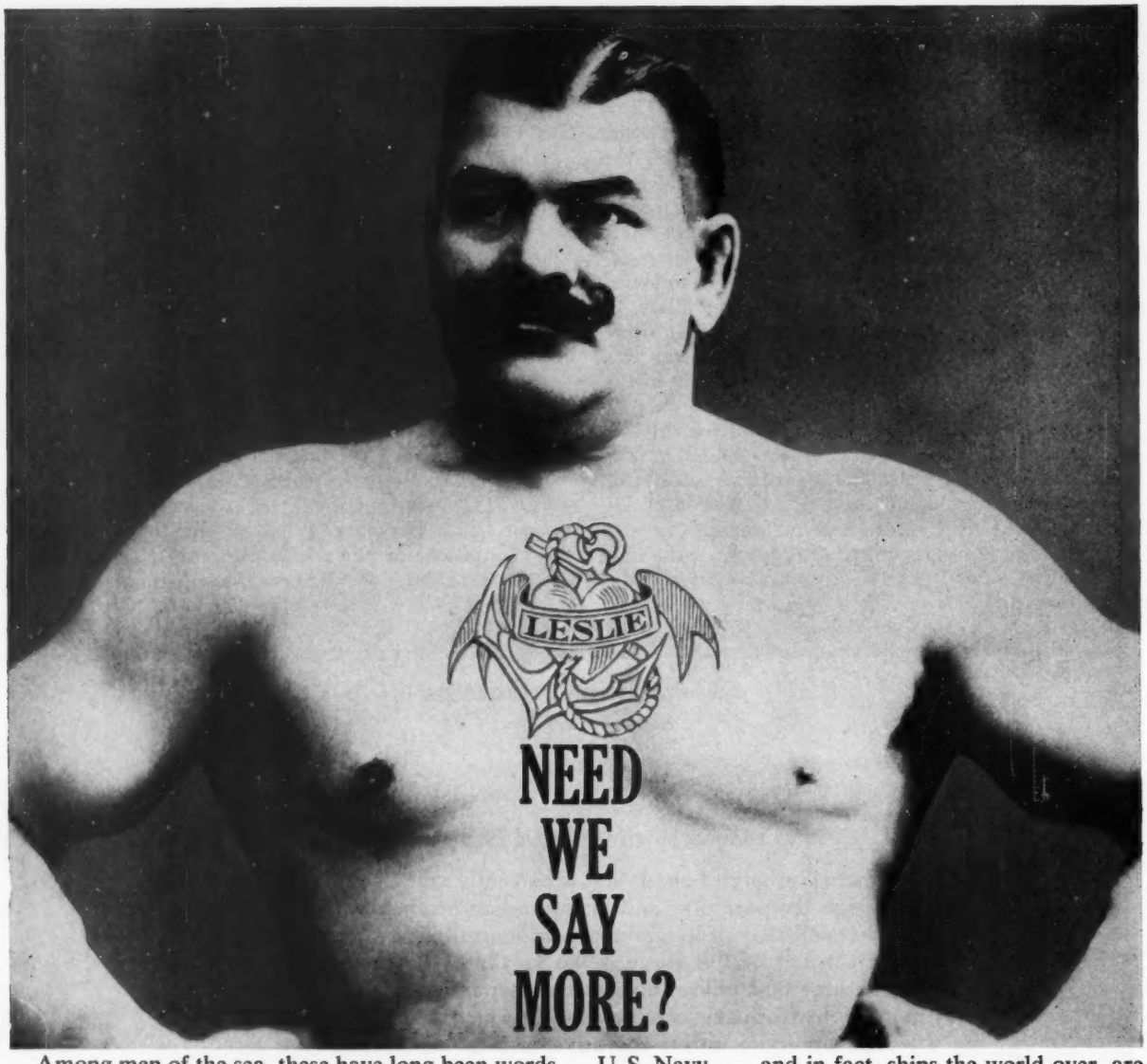
Magnetohydrodynamic Generator

The Armour Research Foundation is currently studying the combustion of coal at high temperatures and the ionization mechanisms, both thermal and non-thermal, that produce maximum ionization in combustion gases. The ultimate result of this study is the feasibility of a magnetohydrodynamic generator that utilizes coal as an inexpensive fuel.

A magnetohydrodynamic generator, in which ionized gases substitute for a wound armature, offers the advantage of converting heat directly into electricity without any intermediate moving parts. This mechanical simplicity would permit greater efficiency than is now possible with the conventional combination of steam turbine and generator. But the ionization necessary for such a generator is ordinarily produced at temperatures too high to be contained by present-day construction materials.

ARF researchers believe that coal may hold the solution to the ionization problem. The ash in coal, usually considered a deterrent to the efficient combustion needed in the magnetohydrodynamic generation of electricity, contains alkalies that, if properly utilized, could aid considerably in ionizing the combustion gases.

FRONTIER 21



Among men of the sea, these have long been words that touch the heart: "home". . ."mother". . ."Leslie Regulators and Controllers."

The members of the Leslie family are held in tender regard especially by those on board or ashore who are responsible for the profits of ship operations. Delays en route due to failure of controls can be costly in cargo spoilage and other ways unnecessary to detail here. The point is that Leslie dependability makes malfunction an extreme rarity. This being more or less common knowledge among shipowners, operators and builders, it's little wonder you find that fully 95% of America's merchant fleet, as well as ships of the U. S. Navy . . . and in fact, ships the world over, are Leslie-equipped.

The picture-summary below of Leslie marine product classifications may help to remind you of all the different ways that Leslie dependability (proved through 60 years) can safeguard your ship design or ship investment. Your request for complete engineering and application data will be welcomed.

LESLIE REGULATORS AND CONTROLLERS

A SINGLE STANDARD OF QUALITY SINCE 1900

LESLIE CO., 709 Grant Avenue, Lyndhurst, New Jersey

ENGINEERED FOR MARINE SERVICE

Diaphragm control valves

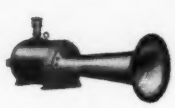
Control pilots for pressure, temperature and level

Pressure reducing valves

Temperature regulators

Pump pressure regulators, Differential pressure regulators

Strainers



Steam and air whistles, automatic whistle controls

"SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS"

SOME ASPECTS OF AUTOMATION FOR SHIPS

ACKNOWLEDGMENT

This article is reprinted from a paper presented to the Philadelphia Section, Society of Naval Architects and Marine Engineers on February 17, 1961. The authors are R. E. Stillwagon, R. M. Mentz, S. A. Haverstick and L. B. Podolsky, all of Westinghouse Electric Corporation.

THE TERM "AUTOMATION" cannot be discussed without reference to "mechanization." The latter term normally refers to the replacement of human or animal power sources through the application of technology. Automation, however, implies any process in which the physical and mental functions of the human operator are taken over by self-acting or control devices. When considered in this form, "automation" is a step beyond "mechanization."

It is possible to visualize "automation" as a four-step building process.

(1) Feedback regulation systems
(2) Coordination of feedback systems with process control
(3) Data logging
(4) Automatic sequencing, programming and computing through digital techniques

The application of steps (1) and (2) above is not new and goes back for almost 300 years. Probably one of the earliest automatic devices was conceived in 1680 when Denis Papin placed a heavy weight on the lid of a pan and so produced the first controlled pressure cooker. James Watt in 1788 designed the centrifugal governor to control the speed of his steam engine, and in 1830 Andrew Ure of Glasgow was granted a patent for a device called a "thermostat." In 1868 the vessel, *Great Eastern,* was fitted with a steam piston steering motor allowing movement of the rudder to be controlled remotely by the position of the helmsman's wheel. The motor also incorporated a follow-up or self-regulating mechanism which progressively closed the steam valve as the rudder moved such that when the rudder came to a rest position, no further steam was admitted to the cylinder.

These are just a few examples of the many automated devices developed through the years. However, their operating principles are the same; i.e., when the controlled quantity deviates from its desired value, controlling action is taken to reduce the deviation.

Technological advances in automatic control in the past, as well as recent developments and utiliza-

tion of electronic computers, data logging equipment, sensing instruments, electronic solid state devices and others, have provided or contributed to the impetus of the automation concept.

Various industrial systems and plants recently automated are proving very successful. Some examples of these are the gas pumping stations on pipelines located in the United States and Iran, steel mill and paper mill processes and electric utility steam power plants. One of the current projects is the automation of the Sewaren Generating Station of the Public Service Electric & Gas Company at Newark, New Jersey.

The Maritime Research Advisory Committee Study [1] points out that labor-management problems will exist as a result of the transitional difficulties caused by technological advancement. However, it is the intent of this paper to discuss and illustrate only the *technical* role of "automation" in the marine industry. The attendant labor problems are not discussed.

PURPOSE OF AUTOMATION

Automation, like any technological advance, must be examined from the standpoint of reducing the unit cost of performing a certain function. It is not satisfactory to automate for automation's sake alone. The two most promising areas for reducing costs in the U.S. Merchant Marine are reducing the turn-around time by improved cargo handling methods and reducing the ship's crew by automation of certain shipboard operations. Of these, the latter would appear to hold the most promise in making the U.S. flag ships competitive with ships flying foreign flags.

A Maritime Research Advisory Committee study has shown that over the 20-year life of a Mariner type ship the savings in crew wages that can be realized by automation of ship operating functions will amount to $8,460,000. In addition, the savings in subsistance due to a reduced crew will amount to another $540,000. The reduced crew will require fewer accommodations, such as living quarters; lifeboats, etc., and this will result in the saving of additional $710,000. On the other hand, the cost of automation must be considered. This cost has been estimated at $1,040,000. Extra maintenance and repair costs due to fewer ship's personnel and more complex equipment will amount to $2,440,000. Increased insurance and stevedoring costs are estimated at an additional $500,000. Thus, automation will result in a savings of $5,730,000 over the 20-year life of a ship. This saving should provide for both increased profits for the ship operators and reduced subsidies by the government. Other studies may vary in the final savings figure but in all studies, it will be substantial.

Aside from these obvious advantages, automation of shipboard operations will result in additional benefits to which no positive dollar value can presently be assigned. These benefits can only be pinned down by comparing cost averages developed through operating experience.

At present, the cost studies indicate that maintenance and repair costs will more than double on an automated ship. A large percentage of this increase is due to less shipboard personnel being available for routine voyage work, such as corrosion prevention, replacement of worn parts, etc. Nothing has been factored into these studies to account for in-port repainting under better weather and working conditions, lasting longer than an at-sea painting—therefore requiring less paint. Also, nothing has been included for the elimination of repairs presently necessitated by human error. It can be argued that automation will include some errors that also will inflict damage, and this is true, but unlike humans, automated systems can be altered so that the same mistake is never repeated.

These presently hard-to-pinpoint benefits are not limited to a single budget expense heading or to a particular area of the ship. For example, automation of the engine room controls should result in greater fuel economy. Automation of navigation should result in less straying from the desired track due to continuous navigation and thus reduce both fuel cost and voyage time. In addition, although studies now show the cost of insurance to be greater for an automated ship due to the greater replacement cost of an automated ship, the premiums could very well decrease as the number of collisions are reduced by more widespread use of electronic gear and the number of personal liability claims reduced because of smaller crews. These and other benefits can only be fully evaluated by comparison after an automated ship has been in operation for several years.

Automation of cargo-handling equipment will decrease the ship turn-around time and result in reduction of freight handling costs. This will not, however, result in a greater competitive advantage over foreign flag merchantmen because the advantages of reduced cargo handling time and costs will benefit merchantmen of all flags.

Automation of cargo-handling equipment will, however, make ships more competitive with railroads and trucks for the coastwise-intercoastal trade. More than half of every dollar of freight revenue received must be spent for loading and unloading ships. Any reduction in these costs will assist greatly in recapturing a large portion of the trade lost in the last twenty years by the U.S. Merchant Marine.

AREAS OF AUTOMATION

Navigation

There are only two conditions which normally require precise navigation—piloting and when operating near other ships. Since this is the limiting case, consideration is given to means of navigation

under these conditions with only one man, the deck watch officer on the bridge, except for periods of actually entering and leaving port when a pilot normally comes aboard or other times such as in heavy ship traffic when the captain is normally on or near the bridge. It is intended that the deck watch officer have the duties of lookout, helmsman, and navigator. To accomplish this will not require new scientific breakthroughs but will require a better utilization of presently available devices and techniques. However, this will undoubtedly entail a certain amount of training in the proper use of these devices and techniques.

To permit the deck watch officer to serve properly as a lookout will require that the helm and navigating duties be easy to perform and cause minimum distraction from the lookout duties. Steering, for years, has been made easier by the application of servo systems to control the steering gear of ships. The bridge should be constructed to provide a good view throughout the entire 360° azimuth. To aid the deck watch officer in the execution of his navigation duties, a radar repeater should be provided in a location that would enable navigation to be performed by superposition. Extensive tests of radar pilotage by methods of superposition have shown an accuracy that is fully as great as that to be expected from the best visual fixes based on [2] pelorus readings.

Several devices have been designed and used for the superposition of charts on the radar scope presentation or vice versa. All of these devices have one presentation stationary while the other is traversed in two mutually perpendicular directions by means of accurate screws. These two screws could be driven in accordance with readings obtained from the gyrocompass and pitometer with adjustable compensation to correct for set and drift inserted by the deck watch officer so that the two presentations remain superimposed. Automatic sensing and realignment can be made of the two superimposed images to take care of set and drift with an indication of the values to the bridge for checking purposes. Since the radar presentation would include any other ship traffic in the area, automatic solution of the point of closest approach and an automatic initiation of or recommendation for evading action would be determined if necessary or required under the "rules of the road."

While normal inshore navigation under this proposed system is performed by radar or other electronic devices, it must be remembered that they will have limitations. The deck officer must continue to collect all the available data, judge its relative merit, and formulate his own conclusions. Other sources of data would include his own experience, his visual observations, the fathometer, and the Loran track which will be described. In addition, for safety reasons, the deck watch officer would have to undergo an intensive training program, during which various failures of automatic equipment would be simulated so that his realization of the failure and his necessary overriding action would be as rapid and correct as possible.

Radar navigation breaks down on ocean crossings due to the great distance to the fixed objects which can be used as radar targets. In the past two decades, great advances have been made in the field of electronic navigational aids for ocean areas. Today, Loran, Decca or one of the several other systems already in existence are installed on nearly all ocean-going ships. Further advances are in progress as evidenced by the navigation experiments underway using a transit satellite. While some of the electronic navigation systems offer greater accuracy than others, it is felt that all the systems are sufficiently accurate for ocean crossing navigation.

Consideration should be given to what is needed by the deck watch officer from the time the ship leaves port until it has completed the ocean crossing and is again ready to enter port. If certain information is automatically provided on the bridge, only the deck watch officer will be necessary. The most effective aid to navigation will be one that plots the position of the vessel continuously. An effective aid should mark a track on a chart so that the navigator can see at a glance his current position in relation to all other points on the chart. This can also serve as a check for inshore radar navigation but will not be as accurate as radar navigation.

Present Loran navigation requires that the operator obtain lines from at least a pair of Loran shore stations and locate the ship's position on a Loran chart. This Loran fix can ordinarily be taken in approximately five minutes. Reading of Loran position and the switching from one set of stations to another can be done automatically. These two inputs can then be fed into a device similar to a Dead Reckoning Tracer (DRT) to obtain a continuous track on a chart. The DRT presently is fed information from the gyrocompass and the pitometer. It should be no great problem to convert this input to Loran readings. A switch can also be provided so that the deck watch officer can reconnect the DRT to gyrocompass and pitometer readings and automatically enlarge the scale in order to use this device as an aid in a man-overboard emergency.

It must be remembered, as in the case of radar navigation, that while a Loran track can be made very reliable, it cannot for safety reasons be assumed to be absolutely infallible. For that reason a periodic check by means of celestial navigation should be made. Here again, a further step could be a completely automatic celestial fix obtained periodically to check the Loran track. As for the inshore navigation case, ship traffic radar solutions could be solved and evasive action, when necessary, could be taken automatically.

With the automatic navigation aid and with the automatic steering already installed on most mer-

chant ships, there should be sufficient time available for the deck watch officer to serve as lookout and to perform periodic checks on the automatic equipment.

Cargo Handling

The water front must present an enigmatic spectacle to the European traveler who enters the United States via any one of our larger port cities. The United States, a country that has long been synonomous with mechanization and progress, can claim relatively little progress in stevedore and marine terminal operations. Until the advent of containerization, mixed general cargo was handled into and out of ship's holds with boom-winch gear in a manner that in principle has evolved little since the age of the square-rigged sailing ships.

Bulk Carriers. Liquid, ore, coal, grain and other bulk cargoes are generally, in contrast to mixed general cargoes, transported very economically in ships whose remarkable short turn-around time in port can be ascribed to up-to-date handling equipment. The latter's rapid loading and unloading capabilities combined with its compatibility in respect to the ship automation concept and current labor practices should give the bulk carriers a head start toward the automated ship.

Liquid cargoes are generally loaded and unloaded by motor or turbine driven pumps that, aside from starting and stopping, require no particular close human supervision or attention. The loading patterns for liquid cargoes can be programmed so that the appropriate valves are operated in a sequence consistent with a specific loading or discharge plan.

Ore, grain, coal and such dry bulk cargoes are generally carried in ships designed for specific cargoes. These cargoes are generally loaded and unloaded by shore-based cargo handling equipment. Aside from opening and closing cargo holds preparatory to cargo handling operations, the ship's crews are not needed in the actual loading or unloading operations. Facilitating the closing and opening of cargo holds by mechanization could save crew labor, as well as decrease the time spent in port.

Mixed General Cargo Freighters:

(a) *Container Ship:* Containers can be transported on almost any type vessel, but to achieve optimum utilization of the containerization concept, a ship specifically designed to transport containers must be used. Container ships now operating, as well as those of proposed design, are equipped or will be equipped with electric-powered gantry cranes for loading and unloading the containers. These cranes are readily adaptable to a degree of automation. The loading and unloading operations can be programmed so that horizontal and vertical movement, as well as the stowage location of each container, are taken out of human control. The loading or unloading sequence of each container can be programmed according to a loading or unloading plan that maintains the ship's stability and trim during the cargo-handling operations, as well as in the final loaded or unloaded state.

(b) *Break-Bulk General Cargo Vessel:* The boom winch powered by an electric motor is standard cargo handling equipment for the break-bulk general cargo vessel. Typical ship boom winches require appreciable time and labor to be set up and ready to operate and to stow ready for sea. It is the preparatory time and labor requirement prior to operation or stowage that renders boom winches incompatible with the reduced manning scale of the automated ship.

Cargo-handling cranes that do not have to be rigged ready for operation and later stowed for sea have demonstrated their capabilitiy to be at least equal to the boom-winch gear.

The adoption of a cargo crane, that can be readied for operation or stowed ready for sea in a short time by one man, in conjunction with the completely mechanized securing of cargo hold hatches, can contribute substantially toward the designed reduction in ship's crews.

Cargo Care

Modern air conditioning, ventilation, refrigeration, dehumidification and other machinery pertinent to cargo care have reliable control and monitoring equipment. This machinery will not require extensive modifications to make it suitable for use in an automated ship.

Anchor Windlass

The anchor windlass should be considered as a component of a system which entails all functions pertinent to the ship's anchors. An analysis of the current anchor handling practices reveals that there are several ancillary functions which must be mechanized and remotely controlled. The chain's gravity can be utilized to achieve proper stowage in the chain's locker without human control or supervision. Present controls must be expanded from the relatively simple local speed and direction control to include an integrated remote and local control for the entire anchor handling system. This control should include such indicators and instruments as may be needed for anchor windlass control from the bridge. Examples: amount of chain out, anchor's position to a specific reference point. The modifications required to reduce the manpower requirements for anchor handling can be achieved by redesign and application of developed control devices.

Engineering Plant

In the engine room of a modern steamship, one finds an array of systems, each designed to fulfill a specific function, and each operating largely inde-

pendent of the others. Many of these systems are under the control of fairly elaborate automatic regulators. The combustion and steam generating systems employ highly developed automatic regulators for controlling fuel-air mixture and flow to maintain constant steam pressure and temperature. The condensate and feedwater system maintains proper vacuum in the condenser and proper water level in the boiler. The electric generating plant has regulators which maintain constant voltage and frequency.

Surprisingly, one of the largest single items of machinery in the engine room, the main propulsion turbine, is more often than not completely operated by hand. Propulsion power is generally controlled by varying the flow of steam through the turbine and this is accomplished by means of a series of valves and throttles all mechanically programmed for operation from one or more large handwheels. Although this is the usual practice. there have been some notable exceptions; e.g., the 255-foot turbo-electric Coast Guard cutters built in 1943 which are equipped for complete speed and maneuvering control from the pilothouse.

If the obvious step of turning over to the bridge (by means of a suitable remote control system) the actual manipulation of the maneuvering valves, the engine room force will be relieved of their only remaining full time task and their duties would then consist of setting up equipment for operation, monitoring its performance, correcting any malfunctions, and occasionally rotating the duty among the various items of standby equipment. This then permits a reappraisal of the duties of the engine room force and the manpower required to fulfill them.

First, it might be in order to examine the philosophy used to arrive at the arrangement of the engine room machinery used in modern steamships. It is presently the practice of marine designers to arrange the machinery for the most efficient use of available space, functionally locate equipment to produce the shortest and simplest pipe and duct runs, and provide at least the minimum amount of space around each component required for operation and maintenance; always under the assumption that there is someone available nearby to perform the required operation at the required time. There is apparently little consideration given to operating convenience or the distance a particular operating valve or switch might be from the watch station. This is entirely reasonable when it is assumed that the normal watch in an engine room consists of a minimum of three men.

An approach to reducing or eliminating the engine room force is to provide a centralized location from which all engine room functions can be monitored and controlled. This involves the installation of remotely operated valves and switches and provision for visual display of all the required quantities requiring monitoring or periodic reading. The step from centralized control to complete engine room automation may not be as great as it at first appears.

Power plant automation employing a control type computer will provide improved plant reliability for shipboard operation. In the electric utility industry the justification for the increased investment in computer control is found in the demand for increased reliability. The growing size of boiler-turbine-generator units and their increased complexity has increased the danger of serious operating errors and has made the resulting damage for a mistake more expensive. The expense comes about not only in the materials and labor required for repairs, but also in the down time of generating capacity. This very fact that new units start and stop only at long intervals is itself an argument for automatic equipment because operators can forget procedures that are used only occasionally. Visual or audible alarms are given when limits are exceeded. Special printout programs can also be initiated giving the numerical values of the deviation from desired levels of any abnormalities. Under certain conditions, such as equipment failure, it is desirable to have a history of events preceding the failure. The computer can be programmed to preserve its readings over the previous ten minutes or the previous ten hours. When an abnormality is encountered, the computer can be programmed to enter an analysis corrective mode of operation in which it examines the surrounding conditions and prints out an analysis of the situation and may take corrective action if so programmed. This will eliminate inadvertent errors caused by hurried decisions and provides increased safety to personnel, as well as reduction or elimination of both minor and major damage to equipment.

During normal operation, optimum plant control is maintained through continuous computer adjustment of subloop control set points. Some examples of self-regulated subloops now used are:

(1) boiler combustion controls to regulate pressure, superheat, water level, feedwater and draft,
(2) auxiliary generator sets—speed (frequency) and voltage,
(3) refrigeration and air condition,
(4) compressor air supply, and
(5) distilling plant.

TECHNICAL ASPECTS OF AUTOMATION

Automation as applied to shipboard use may encompass a wide number of areas depending on the desire or degree of automation required. Figure 1 shows how automation might be applied to some of these areas, such as the engineering plant, damage control, navigation, cargo and cargo care, administration services and other, by integrating into the automation system one or more control consoles and in this particular schematic, a control computer.

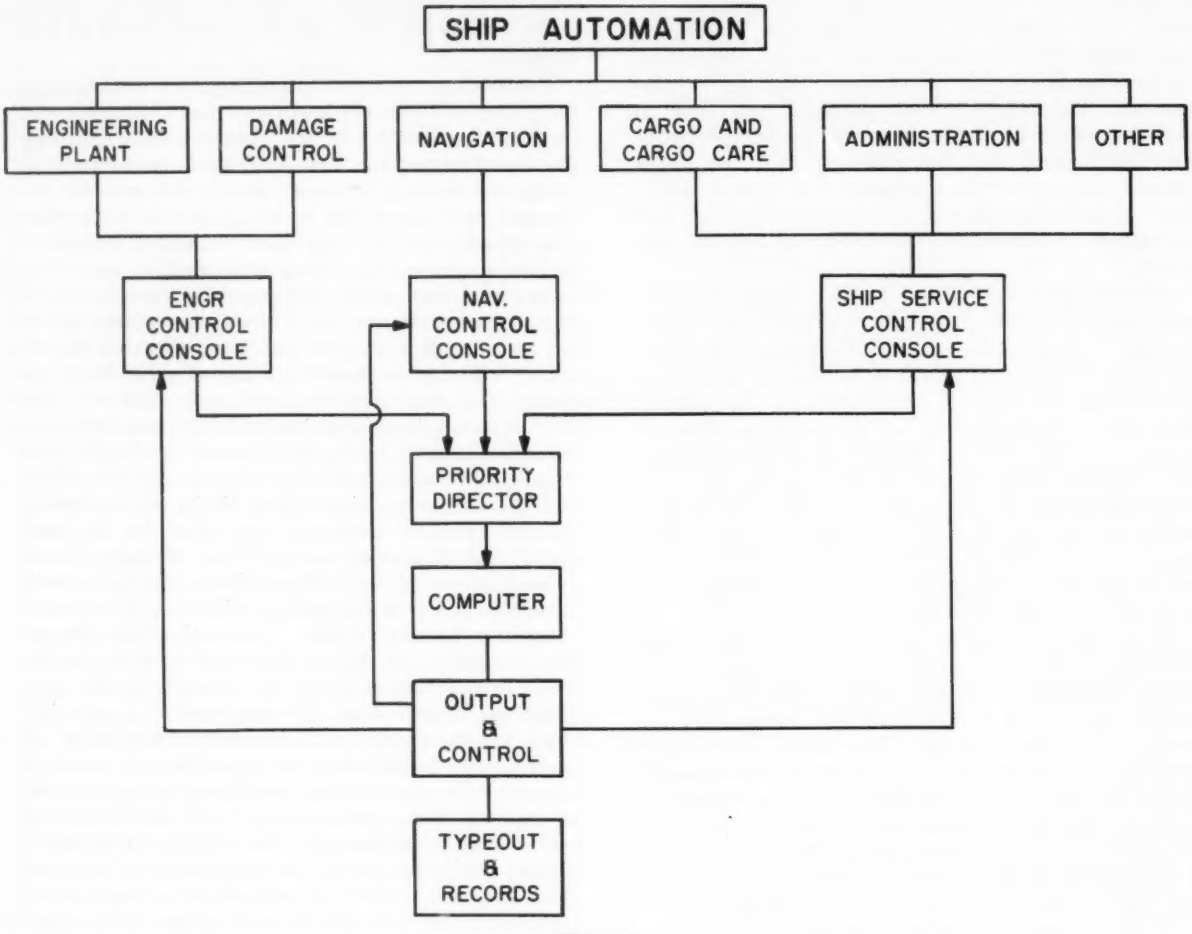


Figure 1.

Complete control would always be available within each specific area through its respective control console but will also allow quantitative and logical data processing and control functions to be performed as predetermined by memorized programs stored within the computer. The information flow path shows input data being directed through a priority director for the purpose of sharing the computer among other shipboard systems.

Figure 2 shows how the engineering plant may be broken down into its various systems and major components; each of which must be studied and evaluated in detail to determine the extent of automation necessary. Again, the flow lines show input information entering the centralized control console and then proceeding to either data logging equipment or a control computer. The latter is further broken down to show an alternate computer utilizing a "wired type program" or a stored program. Both data logging and computer will provide output information; however, new control set points are available only with the computer. Further discussion of the data logging and computer system are presented later in this paper.

As a means of providing a better understanding of automation techniques applied to a typical shipboard engineering plant, boiler operation and the fuel system were chosen as examples and will be discussed in more detail.

It is believed that discussion of a major component and the fuel system will point out, in a limited way, their own control requirements and complexities which when considered with both interacting and non-interacting systems, comprise a major supervisory task.

Marine Boiler Operation

The boiler has four systems associated with it. These are the fuel system, the feedwater system, the forced draft air system and steam system. The fuel system in its simplest form consists of a supply tank, fuel pump, fuel heaters, pressure control and burners. As the fuel requirement increases, the pressure in the fuel line is raised to increase the flow to the burner. Deviation in steam pressure can

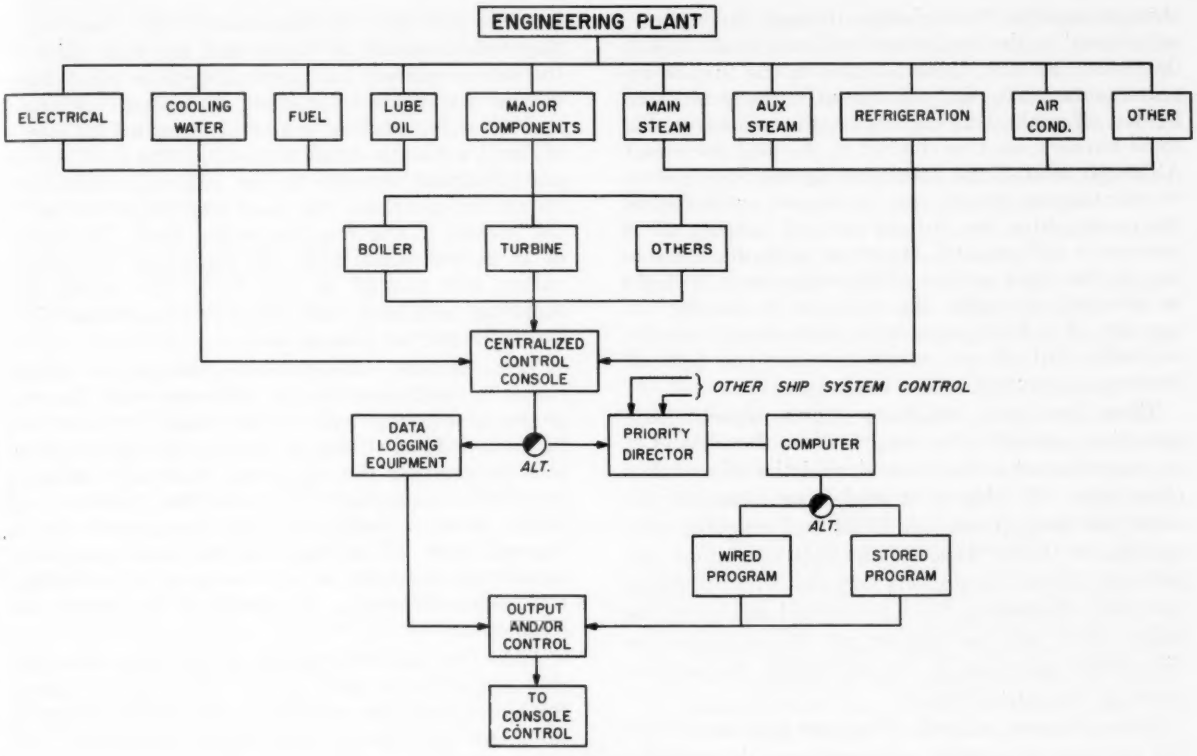


Figure 2.

directly determine the fuel requirements and control the forced draft through the furnace, which in turn controls the pressure on the fuel oil line. There are other possible fuel control systems, some of which might include other factors to determine the fuel pumping rate, such as the feedwater flow.

The feedwater system consists of the condensate pump, deaerating heater, feedwater pump and feedwater heaters. The principal control problem in the feedwater system is that of maintaining the required water level in the boilers. To control the water level, a sensing device detects that the level has exceeded the upper or lower operating limits. At these extremes, the off-limit condition is corrected by variation in pump speed or bypass flow.

The forced draft air flow is controlled by dampers or variable speed blowers. Their setting is determined either directly or indirectly by the steam pressure. If the steam pressure is low, the dampers are opened by means of controlled air or electrical power; thereby, allowing a greater flow of air through the boiler. This change of air flow through the boiler causes a change in the differential draft pressure, measured at points inside and outside of the boiler, which can control the fuel input.

The only steam system requirement is that the steam be maintained at the required temperature and pressure while demands in load vary widely. This control is acquired by means of a signal transmitted from the steam system to the fuel and air draft systems. The signal is responsive to changes in the load. The feedwater input can be controlled by a separate control loop determined by the boiler water level in the steam drum.

Operating Conditions

There are three principal kinds of operation in the engine room aboard ship. These are: (1) the start-up operation of a cold ship; (2) the maneuvering operation; and (3) the steady state condition of operation at sea or anchor.

The start-up operation with a cold ship is one that occurs very infrequently and might be necessitated following repair on the ship's boilers or other parts of the steam plant involving all boilers. This operation requires that the ship be started without steam pressure. The only power available is the very limited amount supplied by the emergency generator to operate essential auxiliaries to start up and fire a single boiler.

The principal control problems of the maneuvering operation, as far as the marine boiler is concerned, are found in the very wide variations in load. As an example, the ship might go from full ahead to stop, or from stop to full ahead. Under these conditions, the steam flow to the propulsion turbines is

changed rapidly. These changes in steam flow require adjustment in the feedwater, fuel oil and air flow to the boiler. In turn, these changes in the fuel oil requirements mean that additional burners must be lighted off as the load requirement increases, or that some burners must be shut off as the load decreases. Although most of the maneuvering operations, such as maintaining proper water level, are automatic on the newer ships, the cutting out and lighting off of burners is still manual. However, with the automation of the major portion of the boiler room, it might be advisable to widen the variation in the fuel oil capacity of a fixed number of burners or to automatically shut off and retract or insert and light off burners as required by the load.

There are two conditions where steady state operation prevails. One occurs when the ship is at sea traveling at a fixed speed, and the other takes place when the ship is at anchor or alongside the dock providing power for hotel and miscellaneous operations. Under these steady state conditions, the principal manual operations performed on the boiler are those of cleaning the burners and analyzing the boiler water and the exhaust gas. There is also the blow-down operation on the boiler and the soot removal in the superheaters.

More distantly related operations associated with the boiler that could be automatic are the periodic pumping of the water and fuel tanks. On the other hand, strictly manual operations on an automatic ship would possibly be the cleaning of strainers in the fuel and water lines since these are relatively infrequent operations and of greater complexity for automating. However, even these operations could be automated if justified.

The manual operations associated with the steady state operation of the boiler system can be eliminated, leaving only the periodic checking of critical equipment to engine room personnel. But even this checking and execution of orderly emergency procedures can be better supervised by a computer.

Cold Ship Boiler Start-up Using Computer Control

The infrequency of cold ship start-up may lead one to believe that this should remain as a manual operation. However, on an automated ship supervised with a computer, the start-up operation can be greatly simplified. Among other things, it completely eliminates the chance of oversight due to complexities in procedure and could reduce most difficulties experienced in the cold start-up operation. To illustrate computer control, the various steps in starting up a cold ship are discussed in the following paragraphs.

The first operation for start-up would be to position and check the various valves to see that the proper ones are opened or closed, as the case may be. For example, the blow-down valve and main stop valves would be closed and the vent valve ot the boiler opened. Actuators to open or close these valves may include solenoid or motor operators, and the valve position would be signalled by means of limit contacts. After a routine check of valves and electrical circuits to see that the plant was ready for operation, the next step might be to fill the boilers to the required water level. By means of an output signal from the computer, the proper valves are opened to the feedwater pump and make-up feed tank, and the water is pumped into the boiler to the desired level.

The next step would be the changes or adjustments in the burner for the cold-start fuel. Because of the infrequency with which a boiler is started up by using cold-start fuel, it would probably be advisable to perform this operation manually unless a completely automatically controlled engine and boiler room is desired. If this operation is to be manual, after all the steps to this point have been completed, the operator will be given a notification and instructions will be typed out for burner adjustments.

After the burner adjustments are made, the next step might be to start the forced draft fan, purge the boiler, and start the fuel pump. After all operations to this point have been performed and checked, a permissive signal would ignite the burner and the warm-up would proceed according to a predetermined program.

It is significant that although the cold start-up is an infrequent procedure, it comprises steps which are performed individually at relatively frequent intervals. For example, boilers are lighted off and fired every time the main propulsion system of the ship is to be used.

Once the boiler has been lighted off, the temperature of the water, metal and brick parts will be increased according to controlled rates determined from frequently monitored sensors. At the appropriate times and temperatures, the boiler vent valve will be closed and the steam valve opened to the fuel oil heaters. At this point it is possible to switch from the starting fuel to the regular fuel oil. The computer will take the boiler up to its regular pressure and temperature according to a prescribed schedule.

At this point the steam lines to one of the main turbine generators will be heated and bled according to instructions from the computer. Then a sequence of automatic operations will be initiated to prepare the generator for use, such as application of steam to the gland seals, starting the air ejectors and pulling the vacuum. Finally, the throttle will be opened to the generator turbine, checks will be made for proper operational conditions, and the generator will be brought up to the proper voltage and phase and placed on the line. This will then

permit the emergency generator to be removed from the line and secured. With the main generator on the line, sufficient power is available for operating the auxiliary or main feed pump, as well as other electrical auxiliaries. The firing of additional cold boilers would be entirely automatic and could be performed with reasonably intricate actuating and sensing devices.

Maneuvering and Steady State Operation with Computer Control

Maneuvering or steady state operation is of particular importance for computer control. In these modes of operation the computer may be used to act as a supervisor for the entire engine and boiler rooms. It will supervise the operation of the automatic control subloops and make any necessary adjustments to them similar to the adjustments that are presently made by the firemen on the fireboard for optimum fuel utilization. The computer would act as an almost perfect supervisor in that it would scan all possible points of any concern in the boiler or steam power plant, and it would scan these points as frequently as deemed advisable. In some cases this scanning might be many times a second to determine a trend or in other cases perhaps only once in minutes, hours or days. In the case of very rapid changes the computer can act on the basis of trends in the course of seconds or fractions of a second. This means that a plant variable, such as the temperature or pressure, does not have to exceed certain fixed settings but that the computer can anticipate the extent to which these settings might be exceeded and act immediately to make adjustments.

In addition to scanning all the critical areas of the steam plant, the computer would also be able to take over the operation of any subloop which failed to function properly. Under such circumstances when the computer takes over the subloop control, an alternate computer program will be initiated to perform the regular scanning function. Also, if a component of the steam plant failed and would not allow the plant to function properly so that it became necessary to shut the plant down, the computer would institute a program for doing this. It would properly sequence the various operations in plant shutdown, including the cooling off of any equipment according to its prescribed cooling schedule. If this became necessary, then the operator at the engine room console would be notified of this condition by the computer and the reasons for the shutdown would be printed out.

Fuel System

In considering the fuel system for automation, it becomes necessary to detail all of the functional operations performed from the time fuel is taken aboard until it is consumed in some combustion device.

Some fuel operations are performed hourly, some daily, others weekly, and others when demanding conditions occur. Only through close supervision, monitoring and planning can the most optimum and efficient utilization of personnel and machinery be made.

The fuel system may be considered to be comprised of four basic operations. These are—

(1) bulk fuel transfer from barge or shore installation to the ship's storage tanks,
(2) fuel treatment for the controlling of undesirable minerals and other contaminants,
(3) fuel transfer to daily storage or settling tanks, and
(4) fuel conditioning for combustion control.

A discussion of each of these operations follows.

Fuel Transfer: The process of taking on fuel in bulk quantities for ship service involves the consideration of a number of factors. The sequencing of operations, in general, requires careful supervision. The fueling process is usually done at frequent intervals, possibly at a number of ports during the vessel's complete voyage. The economics of fueling the ship plays an important part in determining when, where and how much fuel should be bought at any given port of call. Proper scrutinization of scheduling, inventory, and cost analysis can represent a considerable saving to the ship's operator over a period of time.

Usually, fuel is taken aboard from a barge or shore installation. In some instances, such as with naval vessels, fuel transfer is accomplished from another vessel while both ships are under way. Here, coordination and supervision are essential for the successful accomplishment of the transfer process in the minimum time.

In-port requirements are not as severe. However, the onboard functions are equally important and in the case of merchant vessels where economics and increased turn-around speed are desirable, it becomes essential that the fuel be transferred on board as rapidly as possible without spillage on decks or into the surrounding waters.

Once the hook-up is made to transfer fuel, it becomes necessary to properly distribute the fuel through manifolds into appropriate storage tanks. Distribution should be such that no appreciable list is placed on the vessel. Monitoring of level controls and sounding of tanks are necessary to determine the status of fuel transfer and when "topping" is required, flow rate must be reduced at the manifolds when tanks are 85 per cent to allow for some settling time and also careful filling to 95 per cent capacity without overflowing.

Fuel purchased at various ports of call may vary in its specific gravity and chemical composition and requires analysis prior to transfer onboard ship. Excessive water contamination, as well as large percentages of certain minerals, is not de-

sirable and if taken aboard may require extensive fuel treatment prior to its use.

Heaters within the storage tanks would also require monitoring when further transfer is desired to other portions of the fuel system.

Fuel Treatment: When there is sufficient contamination in the fuel, some treatment is provided prior to transfer of the fuel to daily storage tanks. This may involve centrifuging for removal of water, scrubbing or washing of the fuel to remove mineral salts or supplying additives which would enhance the combustion process by controlling the undesirable chemical reactions of other mineral contaminants.

Daily Transfer: After treatment, fuel is transferred to day storage tanks for general consumption in a boiler, engine or other combustion device. It is important that a sufficient supply of treated fuel be available at all times and that any further water contamination as a result of condensation or leakage be detected early enough to prevent carryover to the combustion devices. Suitable monitoring devices and frequent checks are necessary to determine when transfer to another full tank must be made or when the fuel must be re-cycled through bypass systems to centrifuges for further water removal.

Fuel Conditioning: In the final stage of fuel transfer from the day storage tanks to the combustion device, suitable heaters are provided which condition the fuel by temperature control within closely defined limits to insure reasonably constant and optimum combustion conditions.

Further conditioning is achieved by passing the fuel through filters or strainers and removing particles that may eventually lead to clogging of fuel burner assemblies or injectors. Frequent cleaning of the filters/strainers is required for prolonged operation of the system.

These are only some of the more important aspects of the fuel system; one of the many systems which make up the complete propulsion or engineering plant. Under existing shipboard conditions, sufficient manpower is available to perform the functions described. However, with the concept of shipboard automation and consequent reduction in crew, further mechanization and automation will be necessary to carry out the duties normally performed by the engineering personnel.

In considering the fuel system for automation, further examination of the four basic operations which make up the fuel system; i.e., (1) fuel transfer, (2) fuel treatment, (3) day transfer and (4) fuel conditioning, gives a clue to the manner in which automation may be applied and what may be gained by its application.

Scheduling of fuel transfer would be planned so that maximum fuel could be taken aboard at minimum cost. An accurate inventory of all storage tanks would be available from frequently monitored level indicators or other instruments. During the fuel transfer operation, fuel could be taken aboard at maximum flow rates and distributed through the manifold system utilizing remotely controlled mechanized valves. Appropriate subloop controls would determine when tanks are in the "topping" stage and regulate flow rate accordingly to prevent overflow. Distribution would be controlled to maintain stability of the ship at all times by continuous adjustment of manifold valves. Computer facilities could provide rate determination, integrated flow, cost data and increased reliability through close supervision of the subloop controls.

Analysis of the fuel would probably be performed manually; however, various detectors for water contamination or other impurities could be integrated in the system. Results of the analysis and detection could be stored in the computer for use during the fuel treatment process.

In treating the fuel, system complexity and careful monitoring would probably favor computer supervision. Additives would be introduced in closely controlled proportions and scrubbing or washing could be applied for a period of time depending on fuel analysis and rechecking of the fuel treatment process. Subloop control would provide re-cycling of partially treated fuel as well as centrifuge control and automatic transfer to standby centrifuge units when cleaning became necessary.

After treatment, fuel would be transferred to the daily storage tanks where subloop monitoring for high or low level would automatically transfer it to standby tanks. Further detection of a large degree of water contamination would necessitate automatic transfer to standby tanks and re-cycling to the centrifuge.

In the final phase—fuel conditioning for combustion—fuel is passed through heaters as a means of adjusting its viscosity to a desired level. Different fuel compositions will usually have different viscosity-temperature characteristics and will require close supervision and monitoring to maintain the fuel within its chosen temperature operating range. Low fuel temperature makes pumping difficult and results in poor atomization. An excessive temperature could result in a coking condition which will eventually prevent proper passage of the fuel into the combustor. Therefore, maintaining a constant fuel viscosity within the specified limits assures satisfactory operation and reduced maintenance, and optimizes the condition of the fuel for good atomization and combustion.

In this system there are also strainers or filters which require periodic cleaning. Special designs may be adopted which can make these units self-cleaning, if required. Monitoring of pressure drop across these units can determine when a switch-over to clean units should be made and when cleaning is required.

CONTROL TECHNIQUES

To reduce the engineering personnel to a single licensed operator would require the installation of a centralized control console with appropriate displays, warning devices and actuator control buttons or switches. Monitored output signals of the operating components within the system or the self-regulating subloops would be directed into the control console for possible display and then to data processing equipment, such as a data logger or computer.

Data logging equipment would periodically scan the incoming signals, check for normal operating conditions and print out pertinent operational and historical data as required on special typeout forms. In the case of off-limit conditions, provisions would be made to warn the operator by an annunciator or display and to type out the off-limit conditions. Action must then be taken by the operator to correct the off-limit condition since no feedback control is supplied by the data logger to the subloop control systems.

If the degree of automation is such that a computer would best fulfill the requirements of shipboard automation, then the type and size of computer as well as the economics involved will determine whether a wired type or stored program type of computer should be applied. The wired sequence control system, utilizing solid state logic elements, is specifically designed and wired to perform the necessary control, sequencing and operating functions.

The stored program type of control system, utilizing a control computer, would receive the same number of inputs and provide the same number of outputs as the wired sequence control system. However, for large scale and complex procedures the stored program computer has many advantages over the wired sequence type control; a major one being the simplicity of changing the control sequence by modifying the program. Modifying the control sequence in a wired control system requires rewiring of the equipment and probably could not be economically justified in most cases. Some versatility in wired control may be achieved through modular design utilizing plug-in board and printed circuitry. By so doing, program variations may be made by the addition or removal of plug-in boards to modify certain portions of the wired control system. However, the degree of modification would still be limited and the chance of error in the sequencing of plug-in boards is increased by allowing manual interruption of the normal programmed sequence.

In the past, certain special applications of turbine-generator sets have been partially automated for start-up. This automation, however, was by means of a sequenced electrical relay (wired) system. The system automatically started all the auxiliary services necessary before steam could be admitted to the turbine. Root valve, circulating water pumps, oil pumps, air ejectors and condensate pumps were sequenced for start-up. A central steam control panel was arranged with individual switches for each element to be brought into operation automatically in sequence. Failure of any particular element to come into operation would initiate an alarm. The operator could then place the switch for this element in the sequential override position. The operating condition of each element was also indicated by a light system on the control panel. When the light sequence was completed, a signal light indicated that the throttle valve was in condition to be opened. The operator then brought the unit up to speed by remote manual operation of the throttle valve. Bearings were provided with thermocouples for alarm signal, and remote manual monitoring.

When it becomes necessary to adapt a wide variety of control applications such as would be experienced in shipboard operation to computer control or if processing of other types of problems is desired, the stored program control computer would undoubtedly fulfill all of the necessary requirements. The use of a digital computer provides a tremendous capacity to scan, monitor, and perform operations simultaneously. This capacity also makes it practical to consider supervision of functions which normally would be overlooked or not attended to. Duplicating this capability by conventional electrical circuits would lead to such complexity that it would be impractical, if not altogether impossible, to attain.

The computer performs three types of functions in a system; the recording functions, the supervising functions, and the control functions. Figure 3 shows how they would apply to a process control computer. These three types are categorized by the nature of the action taken by the control computer. In performing the recording function, the computer presents tabulated information ranging from raw data to complex process engineering data. Raw data presentation includes periodic printout of system flows, temperatures and pressures. Also, special printout on operator demand is provided. In the supervising function the computer acts as an important link between the system and operator. In the supervising mode the computer rapidly scans input voltages that represent physical variables and compares each scanned voltage with the correct voltage stored as a digital number in the computer memory.

The control functions of a control computer represent the more advanced operations although the sequencing control operation is relatively simple. Sequencing control involves logical decisions in carrying out emergency actions, in starting up and shutting down a process, or in changing the mode of operation of a process.

It must be realized, however, that the installation

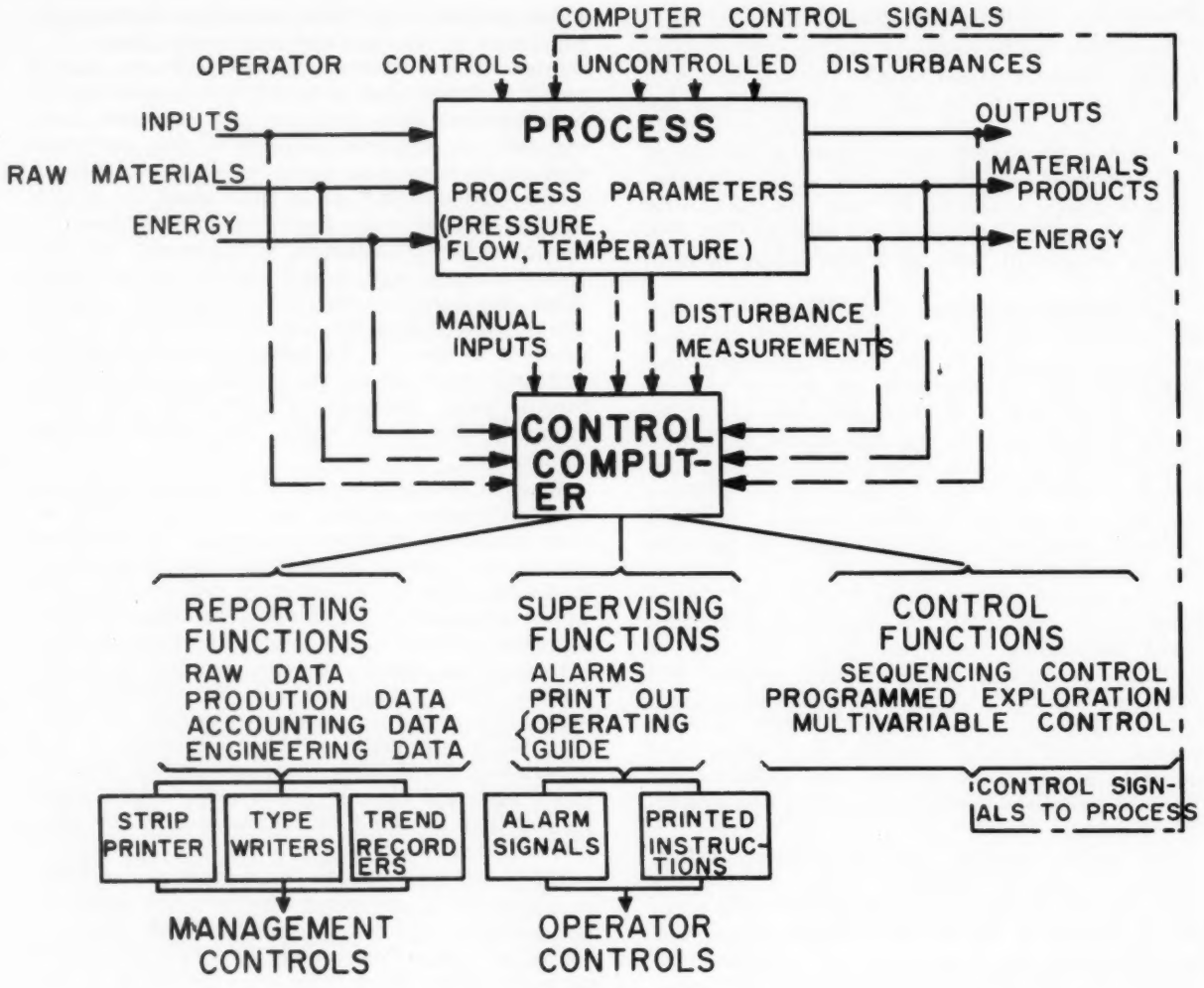


Figure 3.

of an automated system involves more than placing a computer or control coordinator aboard ship. Of course, the computer and its operating console form the heart of the system or control center, but many other innovations are required before it can carry out the desired program. The various systems and subsystems which are to be controlled by the computer must be reviewed and studied with regard to the modifications or designs required to accomplish the following.

(1) Provide actuators to receive control signals for operation. The signals may be a contact closure or an analog voltage from the computer.

(2) Provide sensors to permit monitoring of conditions such as temperature, pressure, position and speed by the computer.

(3) Modification of design to accept additions of (1) and (2) above.

(4) Simplification of existing systems to accommodate the computer program.

(5) For turbines, consideration must be given to the design of suitable supervisory instruments such as vibration meters, eccentricity meters, and spindle position meters. This type of instrumentation has not been used on shipboard and these conditions have heretofore been checked manually. Development of a line of shockproof instruments is required, and this is now being done by the use of magnetic amplifier units. Such instrumentation is required for monitoring turbine conditions, especially during the start-up period.

(6) Development of a system of wide range speed control for operation of the turbine during the start-up program. One system has been developed for central station turbine units which utilizes an electric governor to position a

throttle valve as dictated by the start-up program.

(7) An automatic synchronizer, already developed for land turbine use, can be applied for placing the generator on the load bus.

(8) Due to the decreased number of shipboard personnel required for an automated system, scheduling of maintenance and repairs must be made to meet in-port periods. Probably, a more vigorous and frequent period of maintenance checks must be considered to reduce the possibility of outages at sea.

(9) Consideration must be given to the degree of automation that is feasible from a cost standpoint. Certain small functions or procedures may be handled by one operator, while the cost to automate them would not be economically justified. An example would be the testing of the over-speed trip system. The subprogram to check the trip at start-up would be rather involved. However, one operator could make this check in a few minutes.

(10) Certain subsystems which normally are manually controlled can be adapted to analog control to simplify the computer control. Where an analog control system exists or can be applied, its function is not delegated to the computer. An example of this type system would be the gland seal control which at present is usually a manual control. A control system can be utilized to regulate the gland seal system independent of the computer, and only require monitoring or start-up by the computer program.

REQUIREMENTS FOR CONTROL COMPUTERS

In most business or scientific computers, the speed of computation and input-output operations is dictated not by the nature of the information to be processed but rather by economic considerations. Fast input-output units are provided to utilize efficiently the internal high speed capability of such computers. However, in business or scientific computation, a slow computer would be used since information is processed on an historical rather than a real time basis.

The scheduling of different problems on business or scientific computers is to a large extent sequential. In other words, since the information to be processed by the computer or the scientific problems to be solved are not related to real time, one can wait until the problem that is presently processed is completed before the computer is requested to solve a new problem.

Control computers, although similar to general purpose business or scientific computers in their general organization, differ from the latter in many respects. For example, since control computers handle real time problems, their computational speed is relevant and one can draw a line between problems that can and those that cannot be handled by any one control computer. Since a control computer unit must communicate with an actual real time process as well as with a human operator, the speed, nature and number of input-output devices required are also different from those of a business or scientific computer. The scheduling of different operations in control computers is also different. Since all operations are related to real time and since all operations cannot be performed simultaneously, the computer is "time-shared."

The special requirements of control computers are discussed in more detail in the following paragraphs.

Input-Output Requirements

The area of input-output operations—the means of computer communication with the outside world—is the one area in which the greatest differences exist between business or scientific and control computers. In addition to the conventional input-output devices (paper tape or card readers, paper tape or card punches, line printers, etc.), there is need for the following input-output operations.

Analog Inputs: The process to be controlled by the control computer might have anywhere from a few to several thousand analog continuous variables. The signals representing these variables might be electrical, pneumatic or mechanical. It is necessary that these signals should be sensed by the control computer and converted to a digital form suitable for storing in the computer memory. This conversion is done by an analog-to-digital (A/D) converter. The input to the A/D converter is usually a voltage. Consequently, any variable not in that form requires an appropriate transducer. Since there is only one A/D converter for economic reasons and many input variables, some type of multiplexing or switching in the input of the A/D converter from one input signal to another is required.

Analog Outputs: The control computer exercises dynamic control over the process by computing the values of certain variables for optimum response according to set criteria. These computed variable are in digital form and they must be converted to analog signals. This conversion is done by the digital-to-analog converter. The analog output signals are used either as reference signals for set point controllers or as dynamic variables in the actual control system.

Digital Inputs: Another type of information that the control computer must be able to obtain from the process is digital information. This information can be in two forms.

(1) Pulse signals representing continuous variables, the output of some types of telemetering devices, the output of turbine type flowmeters, digital clock, etc.

(2) Contacts representing the binary state (on-off) of various devices in the system.

Digital Outputs: The digital output requirements of a control computer fall under the same two categories as the digital inputs from the process.

(1) Pulse output signals. It should be possible to use variables computed by the digital computer as inputs to digital telemetering transmitters or other digital devices in the system.

(2) Contact outputs for purposes of actuating external devices such as circuit breakers, valves, displays, etc.

Human Operator—Control Computer Communication

Although general purpose business or scientific type computers have some means of manual inputs by and displays for the operator, the need for such operator-computer communication is much greater in on-line applications. A list of some of the functions that the operator should be able to perform through the operator's computer console is given below.

(1) *Inputs*

Initiate the process start-up or shut-down procedure.

Set decimal values on selector switches and store these in specified computer memory locations.

Initiate or interrupt various input scanning sequences.

Add or eliminate points from any scanning sequence.

Demand logging of any number of input variables.

Request the display of any quantity stored in the computer memory.

(2) *Outputs*

Display requested information.

Activate alarms.

Provide any other information that would help the operator in making intelligent decisions.

Interrupt and Priority Control

In case more than one operation has to be performed at any time, the computer should be able to recognize the relative importance of each and assign a priority order in which operations are to be performed. When an operation is interrupted, the computer should be able to "remember" where it left off so that later it can continue from the same point. A few examples showing the need for interrupt and priority control features in on-line computer applications are given below.

(1) In case of a plant emergency detected by the closing or opening of a contact or a combination of contacts, the computer should immediately interrupt its present operation and proceed with an emergency shutdown program.

(2) In case of a significant computer failure detected by self-checking circuits, the present computer operation should be put under manual control.

(3) The operator should be able to interrupt the present computer operation in order to make changes in values of constants and variables through the operator's console.

(4) If it is required that operation (for example, logging) be performed at a particular time, then the clock should be able to interrupt whatever operation happens to be going on (provided it is not of higher priority) and initiate the logging operation.

Computational and Logical Requirements

An efficient control computer system is obtained by a special design with control applications in mind, since not only the input-output requirements are different but also the requirements for some arithmetic and logical operations, as well as information transfer within the system as contrasted to a general purpose computer. The special requirements for the internal organization of control computer units are shown in Figure 4 and are described below.

Control Unit: Since input-output operations are much slower than the internal computation, it would be desirable to have the arithmetic unit function independently of the input-output units. Information would be transferred directly be-

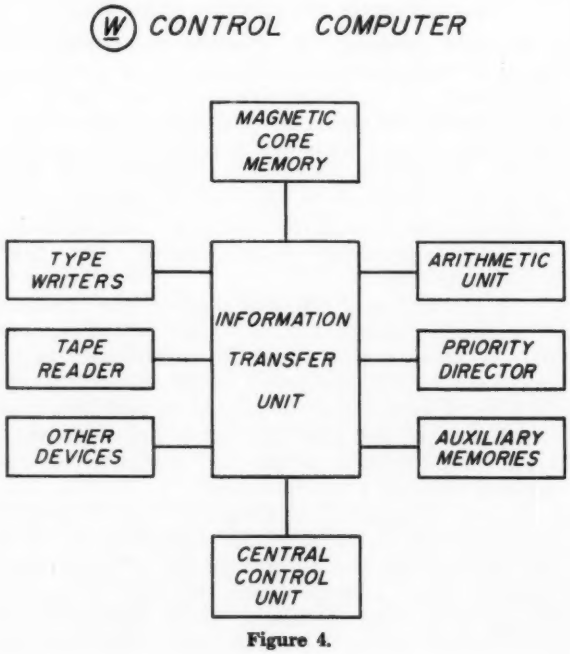


Figure 4.

tween input-output units and memory without going through the arithmetic unit. The function of supervising this additional information transfer would fall on the control unit.

Arithmetic Unit: In addition to the conventional instructions, the arithmetic unit of a control computer should be able to execute other instructions related to the peculiar nature of input and output devices. For example, since the results of the analog-to-digital conversion are accurate to about 0.1 per cent or three decimal places, it should be possible to store such results only in a fraction of a memory location, thus utilizing memory space efficiently. The arithmetic unit should also be able to handle contact closure information efficiently.

Priority Unit: The special need for a priority unit was mentioned under input-output requirements since the interrupt signal can be considered as an external input. However, the presence of a priority unit affects the internal organization of the control computer extensively. Special instructions should be provided which would make it possible to upgrade or downgrade the priority of certain operations. Provisions should also be made for the computer to remember at what point in an operation it was interrupted.

Structural Requirements

The need for reliability of control computers cannot be overemphasized. In an on-line computer an error at the right place and time might cause considerable damage. For this reason the design of control computers should aim at the highest reliability possible and should provide means for checking—both through hardware checking circuits and through diagnostic programming. Since the environment where most industrial control computers are installed is quite different from that of business or scientific computers, control computers should be designed to operate under less favorable conditions of voltage fluctuation, noise pickup, temperature, vibration and dirt.

CLOSURE

The near future holds great promise for the application of automation to the marine industry through continuing developments in machinery reliability, mechanization and control techniques. Full automation may well come about in an evolutionary rather than a revolutionary manner. In either case, it is hoped that the information presented in this paper will stimulate discussion and accelerate the initial step of a series leading to the ultimate realization of a fully automated ship.

REFERENCES

[1] Proposed Program for Maritime Administration Research, Vols. 1 and 2, 1960. Prepared by: Maritime Research Advisory Committee; National Academy of Science; National Research Council.

[2] "Radar Aids to Naviation." MIT Radiation Laboratory Series.

[3] "An Analysis of Shipboard Cargo Cranes," by F. G. Ebel.

GIBBS & COX, INC.

NAVAL ARCHITECTS AND MARINE ENGINEERS

NEW YORK

USS Bainbridge glides smoothly into Fore River after her launching at Bethlehem's Quincy Yard. In the background is the yard's huge building basin with three tankers, ranging from 46,000 to 106,500 dwt, under construction.

USS Bainbridge

FIRST NUCLEAR-POWERED, GUIDED-MISSILE FRIGATE

On 15 April 1961, the USS Bainbridge (DLG(N)-25), our Navy's first nuclear-powered, guided-missile frigate was launched at Bethlehem Steel's Quincy, Mass., shipyard.

Scheduled for delivery in mid-1962, approximately three years after her keel laying, the Bainbridge has an overall length of 564 ft., breadth of 57 ft. 10½ in., depth of 32 ft. 3 in., and a loaded displacement exceeding 7,600 tons. Twin reactors will provide this twin-screw frigate with unprecedented range and maneuverability. Her armament will include twin surface-to-air Terrier missile mounts and the most modern anti-submarine weapons.

She bears a fitting name for the Navy's first nuclear destroyer-type warship. The first destroyer ever built for the U. S. Navy (DD No. 1) also bore the name of Commodore William Bainbridge, hero of the Tripoli Campaign and the War of 1812, and commander of the frigate Constitution when she defeated the British frigate Java.

Following her launching, the new Bainbridge was towed to an outfitting slip in the Bethlehem yard. Nearing completion nearby was the nuclear-powered, guided-missile cruiser Long Beach, also the first of her type.

Their silhouettes unbroken by smokestacks, because they are nuclear powered, these warships represent more than just a new look for our new Navy. They have striking power and cruising range potentials without parallel in naval history.

SHIP REPAIR YARDS
Boston Harbor — New York Harbor
Baltimore Harbor — Beaumont, Texas
Los Angeles Harbor — San Francisco Harbor

SHIPBUILDING YARDS
Quincy, Mass. — Beaumont, Texas
Sparrows Point, Md. — San Francisco, Calif.

FOUNDRY and PROPELLER PLANT
Staten Island, New York

BETHLEHEM STEEL

Shipbuilding Division

GENERAL OFFICES: 25 BROADWAY, NEW YORK 4, N. Y.

Telephone Digby 4-3300 — Cable Address: BETHSHIP

"VECTORS"

COLIDAR

ACKNOWLEDGMENT

This staff article appeared in the second quarter 1961 issue of the Hughes Aircraft Company publication "Vectors" from which it is reprinted.

LITTLE MORE than six months ago, announcement was made of invention of the laser—a device achieving true amplification of light waves for the first time in scientific history. Greatly improved optical radars and the opening up of an enormous number of communications channels were forecast as among the laser's most far-reaching applications.

Today, justifying predictions, the first significant practical application of the laser (derived from "light amplification by stimulated emission of radiation") has been successfully demonstrated. Although in early stages of development, this first optical radar already provides a coherent light beam 100 times narrower than beams of ordinary microwave radar systems.

Radar "pictures" made with the laser system are exceptionally sharp, revealing far more detail than previously obtainable. For example, the optical radar recently demonstrated can distinguish between two adjacent 10-foot objects at five miles. Further, the enhanced resolution is obtained with equipment of small size, (and therefore much lighter weight) because light waves can readily be focused by lens-and-mirror systems, whereas ordinary radar microwaves require immense antennas to focus the radio energy into comparably narrow beams.

This latest advance in practical application of the laser principle is the work of a science/technology team headed by Dr. George F. Smith of the exploratory studies department, Hughes Research Laboratories, and Dr. Malcolm L. Stitch, senior staff consultant of the Hughes Radar and Missile Electronics Laboratory. The new radar, also known as "Colidar," was described March 23 of this year by Dr. Smith to the annual convention in New York City of the Institute of Radio Engineers. It is oriented toward ultimate spacecraft and satellite use.

As envisioned by laser inventor Dr. Theodore H. Maiman (*Vectors,* Vol. II, No. 4, 1960), laser radars should be especially valuable for use in space, where size and weight are critical—but where there is no absorption or scattering of light rays by rain, clouds or by the atmosphere itself. It follows that in many space applications, stray sunlight which might overwhelm the light pulse detected by the laser radar receiver can be avoided. With the exceptionally narrow light beam practical with laser systems now, it will be entirely feasible to illuminate a spot only 10 miles in diameter on the moon's surface. Far more accurate mapping of lunar topography is one consequence not far away.

Creation of the laser radar traces back to the invention by Professor C. H. Townes of Columbia University in 1955 of a solid-state device which he termed a maser (now accepted to mean "molecular amplification by stimulated emission of radiation"). Natural properties of atoms or molecules are utilized by the maser in interacting with electromagnetic radiation. The results are effective in the microwave area of the spectrum, where Hughes solid-state maser devices were early used as amplifiers in X-band radars and satellite communication systems (*Vectors,* Vol. I, No. 1, 1959).

THE LASER RADAR SYSTEM

For radar operation, a short burst of red light from the laser is "aimed" or directed at a "target" to be detected. Light reflected back from the target is gathered by a telescope and detected by a light-sensitive phototube. Distance to the target is determined by measuring the time required for the light-burst to make the round trip. Elements of the system are seen in the block diagram shown in Figure 1. The electrical signal resulting from the light-pulse returned to the receiver is displayed on a cathode-ray oscilloscope. Time delay for the distance measurement is obtained by comparing the received signal with a sample of the transmitted light-burst as monitored by a reference phototube. Figure 3 illustrates the Hughes experimental laser ranging system.

Key element of the new optical radar is its ruby laser light source (Figure 2). The device is also sometimes called an "optical maser." The ruby crystal is "driven" by a flash of white light from a powerful xenon flash tube similar to those used in a type of electronic photoflash gun. When illuminated or irradiated in this way, the ruby produces an intense burst of pure red light in an extremely narrow beam.

Although lasers eventually should provide beams as narrow as 0.004 degrees without the aid of lenses, the laser used in the Hughes experiments emitted a 0.7-degree beam due to inherent imperfections in the ruby crystal. In order to further reduce the beam-width, a telescope with a six-inch mirror was employed. Providing a 40-fold improvement, the telescope resulted in a system with a 0.023-degree beam. When the system was directed at a building three-and one-half miles distant, the beam of light's "spot" was only seven feet in diameter.

The present laser transmitter operates with peak powers up to several kilowatts at a wavelength of 6,943 angstroms, or 0.00006943 centimeters. (One angstrom unit is equal to one hundred-millionth of a centimeter.) An important feature of the system, allowing substantial improvement in the ability of the receiver to reject ordinary sunlight, is the fact

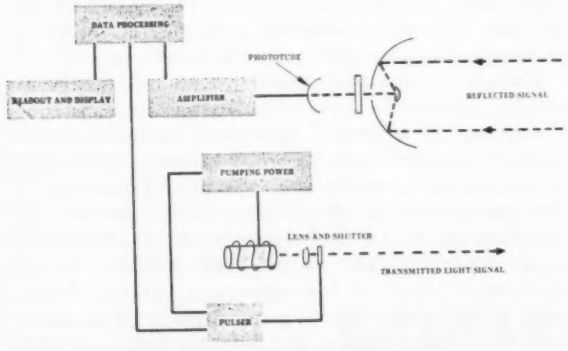


Figure 1. Block diagram of laser radar.

Figure 2. Heart of the laser.

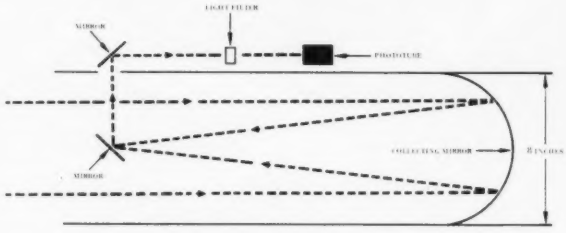


Figure 3. Laser receiving system.

that the laser output is extremely monochromatic, i.e., consisting of one color or hue. All of the output energy is concentrated in a 0.1-angstrom-wide spectral band at the wavelength mentioned, thus permitting a narrow spectral filter to be used at the receiver.

For ideal microwave radar performance, the transmitter output should consist of a single short pulse. The pulse preferably should last for a few microseconds, or a few *millionths* of a second. However, present ruby lasers provide output bursts consisting of many closely-spaced short pulses occurring over a period of about 1,000 microseconds. Improvement already has been obtained in the electronic "shape" of the output burst by cooling the ruby (the "heart" of the laser) to about −150°F.

One of the principal components of the laser ranging system is the receiver. Here light is gathered by another telescope, with a five-inch lens. The larger the telescope's diameter, the more sensitive the receiver. Light entering the telescope is first passed through a red filter which does not impede the 6,943-angstrom radiation from the laser, but which does reject 99.9 per cent of the light from all other ordinary sources—such as sunlight, light from incandescent lamps, etc. Light passing through the filter is then directed at a very sensitive phototube where it is converted into an electrical signal for display on the oscilloscope. A photomultiplier-type of phototube provides a very sensitive detector. (See Figure 1).

Initial significant ranging experiments were conducted against the white stucco wall of a building three-fourths of a mile away. In subsequent tests, ranging was accomplished at two miles in full sunlight and at seven miles at night. Figure 5 is a reproduction of a photograph showing radar return at seven miles. Such relatively short distances are far short of the ultimate capabilities of the system.

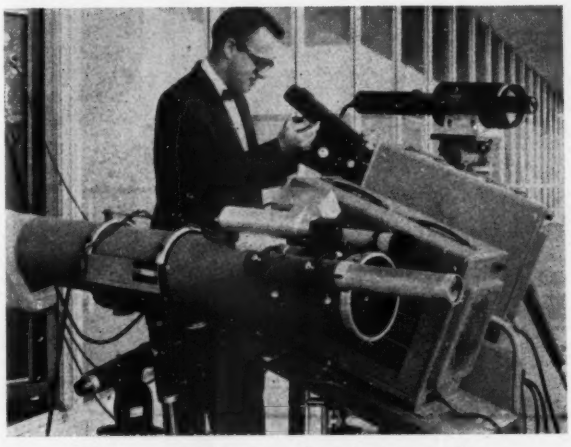


Figure 4. Hughes experimental laser radar.

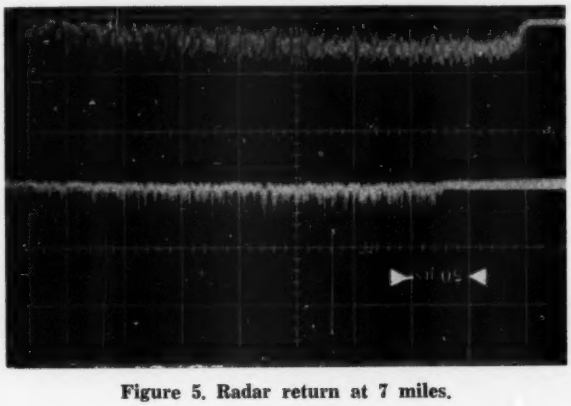


Figure 5. Radar return at 7 miles.

Operation at much greater distances may be expected with improvements in design and with further laser developments.

Rough calculations indicate that only two or three orders of magnitude improvement in the system would be required to obtain detectable pulses from the surface of the moon. Refinements already well under way include higher power lasers operating with shorter bursts (to reduce problems from "backscatter" from dust and water particles in the air), more sensitive receivers, and improved optical systems.

THE MATTER OF "NOISE"

As with any radar system, the basic limitation in performance that can be achieved by the laser radar is determined by the "noise" level through which the signal must be detected. Three types of noise affect the system: internal or receiver noise; external noise due to unwanted light entering the receiver through the red filter; fluctuation or "shot" noise in the signal itself.

Receiver noise is due to "dark" current (current flowing in the absence of any light) in the phototube. This current is produced by thermionic emission from the sensitive photosurface and can be essentially eliminated through refrigeration of the photocell. However, dark current noise at room temperature is low enough to be neglected with present-day systems.

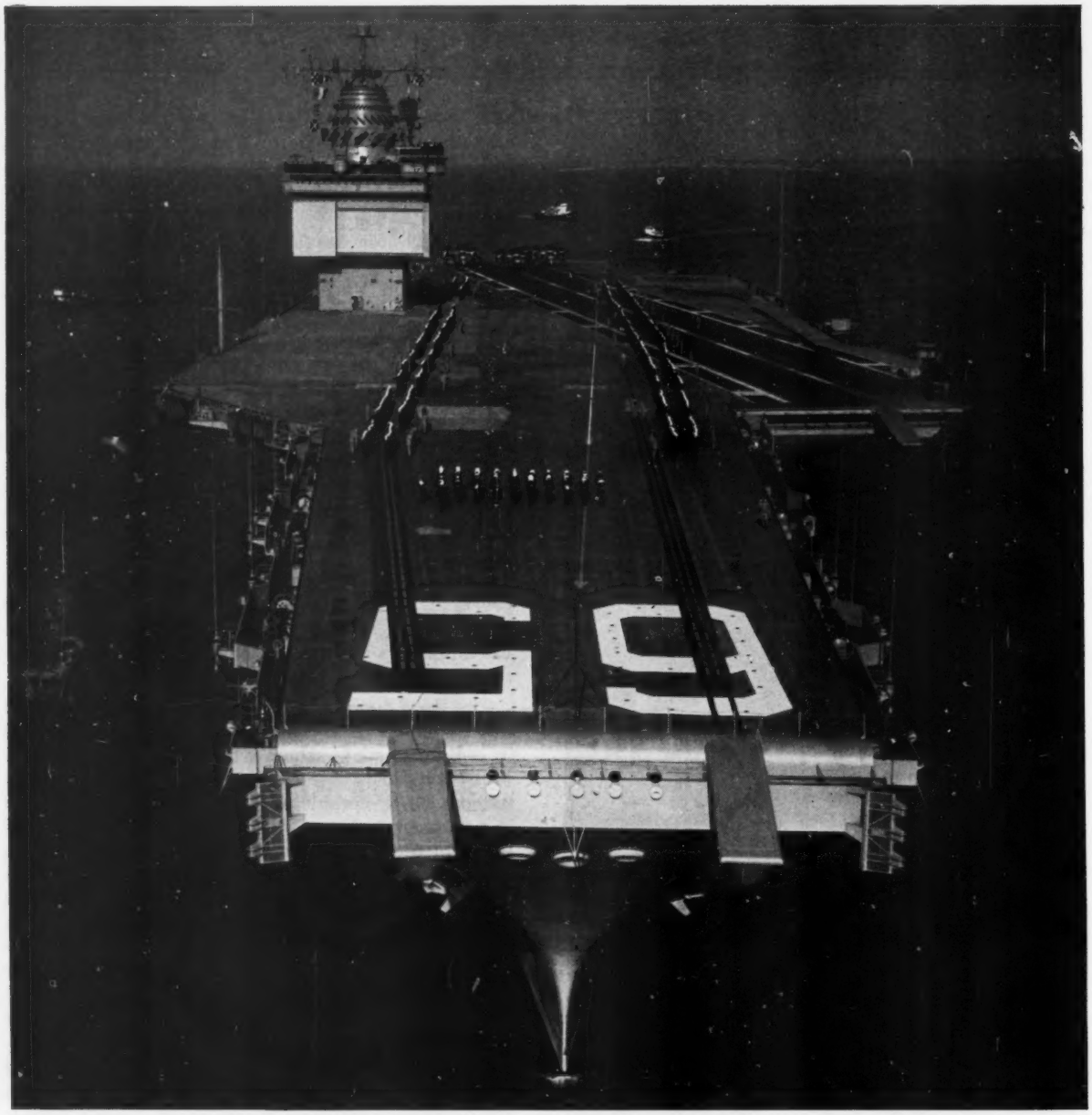
Secondly, for daytime operation on earth's surface, that part of the scattered sunlight which can pass through the red filter imposes the limiting noise for the system. This has been reduced by using a 155-angstrom interference-type filter. Moreover, similar filters with spectral bandwidths as narrow as one angstrom are feasible today. Further improvement will have to await advancement of exotic receiving technique using detectors other than the simple phototube.

An example of the latter might be an optical heterodyne receiver based on the mixing of a local laser signal with the signal to be received, with further selectivity provided in an IF amplifier. Filtering with a narrower bandwidth may also become practical with evolvement of a laser preamplifier which would operate in a fashion analogous to the RF amplifiers customarily used in today's radio receivers.

The third type of system noise comes from signal fluctuation—a new kind of noise not encountered in ordinary radio—which would be still an ultimate limitation for a laser radar even if the other two sources were completely eliminated. Fundamental in nature, it is due to the random rate of arrival of the light photons (basic unit of light energy) which make up the received signal. Noise of this kind can be understood in a qualitative way by recognizing that at least one photon must be detected at the receiver during the time interval when a signal is expected. It represents an ultimate "minimum detectable" signal power, and is likely the phenomenon which will be the working limitation for some of the optical systems of the future.

Lasers will be used to accomplish many useful tasks, some of which can even now be clearly identified. Micromachining instruments, surgical tools for extremely delicate operations, standards measurements, etc., are among possible industrial and professional laser uses. The recent invention of a continuously operating gas laser (as distinguished from the *pulsed* ruby laser) greatly enhances the usefulness of light waves for communications purposes. This is particularly true in the realm of space. The *coherent* properties of laser radiation offer promise for the transmission of fantastic amounts of information at comparatively moderate expense. An optical heterodyning technique, or its equivalent, will still be required to reach the goal.

Nonetheless, those working with lasers now believe that the laser radar will be among the first practical applications of the new device. The experiments described here indicate how close is the realization of a radically improved radar.



ENTERPRISE . . . at NEWPORT NEWS
a word with a double meaning!

To most people, it means the world's first nuclear-powered aircraft carrier. To us at the Shipyard, it means the energy, imagination and resourcefulness that delivered the great *Enterprise* nine weeks ahead of schedule—in many months less time than was taken to build some non-nuclear ships of her type.

Because of her eight reactors and extensive electronic system, no shipbuilding job was ever more complex. For 1,366 days, many constantly-changing challenges were met and surmounted. How well the men, methods and machines of Newport News discharged their responsibility for building the world's largest ship is now a matter of public and official record.

This is *enterprise at Newport News* . . . leader in shipbuilding and in the manufacturing of water power and other heavy industrial equipment.

Newport News
SHIPBUILDING AND DRY DOCK CO. NEWPORT NEWS, VIRGINIA

DONALD JAMES

NAVY LEADERSHIP IN THE DEVELOPMENT OF RADIO COMMUNICATION

THE AUTHOR

a radio engineer and communications consultant, is an electrical engineering graduate of Columbia University. His early work on the development of electron tubes and radio components carried him eventually into the broader field of communications system engineering. He has authored a number of technical papers and talks, and has taught courses in radio waves and circuits. Long interested in Navy and marine radio, he served in USNR during the second world war.

In the article below, Mr. James surveys the related histories of radio and the Navy. He is certain that the technical achievements and adventures of the past are forerunners of still more exciting developments yet to come.

THE SCIENCE of radio communication owes an everlasting debt to the U. S. Navy. Not only have Navy service and civilian personnel contributed to the technical development of radio; the Navy has also encouraged private inventors and industrial corporations to persevere in advancing the field since the earliest beginnings of wireless. The 'Father of Radio' Dr. Lee de Forest, in the dedication of his autobiography, expresses his gratitude "to the United States Navy, which was always prompt to use my new wireless and radio devices . . . and whose Admirals never failed to give me welcome encouragement when it was most sorely needed."

The Navy has always recognized in radio an answer to the need for quick, reliable communication to and between ships dispersed and deployed at great distances. Thus Lieutenant Bradley Fiske, USN, was experimenting with ship-to-ship wireless communication, using inductive coupling between huge loops wound around the vessels, as early as 1888.* When Marconi came to America in 1899 seeking a market for his newly-invented wireless telegraphy, forward-looking Navy officials arranged to have him install his apparatus on the *New York* and the *Massachusetts*. Marconi himself operated the equipment on the *New York* as Rear Admiral Farquher sent the first official wireless message to Navesink, 20 miles away, for relaying to Rear Admiral Phelps at New York Navy Yard. Using a spar lashed to the topmast as an antenna, the two ships were able to exchange messages over 36 miles of water.

Other field tests of various wireless telegraph systems were carried out during fleet maneuvers, and naval officers were sent to Europe to study the wireless art of foreign nations. Promising systems

* Lieut. Fiske subsequently invented the radio-controlled torpedo.

were recommended for trials at the wireless test stations established in 1902 at Annapolis and Washington. (A near-tragic occurrence during these tests provided the first "news scoop" for wireless. Secretary of the Navy Long was seriously injured at Annapolis when his carriage horses ran away. This news was flashed to Washington, where the wireless operators telephoned the details to newspaper offices long before the news arrived over the wire lines.) In the spring of 1903 the tests resulted in selection of the German Slaby-Arco apparatus for installation in twelve battleships of the North Atlantic Fleet. The Slaby-Arco system of that era, which was also adopted by the German navy, used a spark transmitter employing a mercury-jet interrupter, and a self-restoring coherer for detection. This equipment, put to test in sham battles on Long Island Sound during fleet exercises the following autumn, demonstrated the value of wireless communication in naval operations.

By the end of 1904, thirty-three Navy ships had been equipped with wireless, and the Navy was operating twenty shore stations. Commercial stations, too, were mutliplying; the growing congestion of the ether indicated a need for Federal control of the air waves. Therefore President Theodore Roosevelt directed that the Army should control all military stations in the interior of the U.S., while the Navy controlled all military coastal and overseas wireless installations. (Commercial stations were placed under the Department of Commerce and Labor.) This directive, firmly establishing the Navy role in wireless communications, confirmed the leadership in radio that the Navy held and was to maintain through the years ahead.

In 1904-1905 the Navy erected five of the most powerful wireless stations constructed up to that time. Spark transmitters of 25 kw input rating were installed at Key West, San Juan, Guantanamo, and Colon; and Pensacola was equipped with a 10-kw transmitter. These were pioneering installations in the truest sense of the word. At Colon, Goethals and Gorgas were just starting to stamp out yellow fever and dig the Panama Canal. At Guantanamo, where the Navy had only recently acquired a naval base and coaling station, Admiral Rogers still had his headquarters aboard the old *Amphritite* out in the bay, for the insects and mangrove were not yet wholly tamed.

The Navy gave enormous impetus to the development of American wireless (as distinguished from British, Italian, French, or German) when the Bureau of Equipment installed U.S. apparatus on the *West Virginia* in 1905. The successful performance of this equipment during the cruise of President Roosevelt from New Orleans to Washington received wide-spread publicity and generated great interest in American wireless circles. Moreover, this effective demonstration led American maritime companies to appreciate the utility of wireless. Steamship lines, coasters, tankers, and towing firms raced to equip their fleets with the simple detectors and headphone receivers that characterized U.S. equipment; the coherer and ink tape-printer became restricted to foreign vessels.

A dramatic "first" in radio occurred when the North Atlantic Fleet was equipped with wireless telephony (voice radio) in preparation for its round-the-world cruise under Rear Admiral Evans in 1908. The first installations, on the *Connecticut* and *Virginia*, were tested in the fall of 1907; speech was transmitted and received at ranges as great as twenty miles. Said Admiral Evans, "If there is one thing more than another in the fleet of which I am proud, it is the wireless telephone . . . The sailing of the fleet and the flotilla (sixteen battleships, six destroyers, and two auxiliary vessels made the globe-girdling trip) will mark a new era in maritime communications and is just ground for pride to every American that the United States Navy is the first to adopt and demonstrate this new method, and on such a comprehensive scale."

The change in nomenclature from "wireless" to "radio" took place in 1912. The Navy, feeling that the word "wireless" did not make clear that communication was by radiated impulses rather than by induction effects, ordered use of the terms "radiotelegraphy" and "radiotelephony." The new name caught on immediately with the American public.

One of the great experiment stations of early radio was the Navy's Radio Arlington, with call letters NAA, at Arlington, Virginia. Three steel masts—one 600 feet high, the other two each 450 feet high—supported its giant antenna. At its commissioning in 1912, NAA was equipped with a 100-kw Fessenden synchronous spark transmitter, and a Poulsen arc was soon added. Even before the official opening of the station, Morse signals from the Eiffel Tower were picked up on a wire stretched from ground to the top of the 600-foot tower, and by 1914 Arlington and the Eiffel Tower were exchanging special time signals in a precision measurement of longitude differences. A year later, when vacuum tube transmitters were first introduced, the Arlington antenna was used (fed by 500 vacuum tubes in parallel) for the historic A.T.&T. voice transmissions to Paris, Panama, and Honolulu. NAA enjoyed a long and useful carreer as a keystone in Navy communications until its disestablishment in 1956.

With the outbreak of war in Europe in 1914, a Naval Communications Board was appointed to reorganize the naval radio services. On recommendation of the board, the Naval Communication Service was organized in 1915, with Captain William Bullard as its first Director. The Communication Service acquired vast facilities after U.S. entry into the war, when President Wilson directed the Navy to take over all radio stations in the U.S. and

its possessions except those already under Army control. Among the stations thus acquired was the Marconi Wireless Telegraph Company facility at New Brunswick, N.J. Outfitted with a 200 kw Alexanderson alternator transmitter, this station, assigned call letters NFF, was the most powerful in the world. Ships all over the globe could hear NFF, and so could troops on the battlefronts with field receivers. Messages from President Wilson to the German people were broadcast from NFF to the radio center POZ at Nauen, outside Berlin.

To achieve adequate radio communication from France to the U.S. was more difficult. The most powerful stations in France, at Paris and at Lyon, were equipped with only 40 kw transmitters. Lyon gave better reception in the U.S. because of the direction of its aerial, but interference was too great for reliable communication even after the Navy established a receiving site at Bar Harbor, Maine, to get close to Europe and far from the tropical sources of radio noise. To ensure reliable communication from the armies of the American Expeditionary Force, the U.S. government decided to erect a powerful transmitting station in France. The task of building the station was assigned to the Navy, in accordance with the Roosevelt directive; so the Navy, in collaboration with the French Signal Corps, built the famous Lafayette radio station near Bordeaux. Two 500-kw arc transmitters fed an inverted L antenna supported by eight 835-foot towers, giving a strong signal all the way across the North American continent. Begun in 1918, Lafayette went on the air in 1920 and proved of great value for communication with the postwar occupation forces.

In addition to operating radio stations, the Navy was active in many developmental phases of radio during World War I. Oxide-cathode vacuum tube detectors, radio direction finders for seaborne use. aircraft radio, radio controls for remote mechanisms, and many other devices were brought into operational status. Much of this work was directed by Commander Stanford C. Hooper, who, as a young midshipman, had been an interested observer of the Annapolis-Washington wireless tests of 1902-1903.

After the war the Navy, reluctant to see America's radio communication facilities returned to foreign-controlled interests, suggested that a domestic communication company be organized. With the help of the General Electric Company, the Radio Corporation of America was organized to purchase the assets and business of the Marconi Wireless Telegraph Company. At the suggestion of Captain Hooper, RCA and GE entered into a cross-licensing agreement to eliminate patent conflicts that stood in the way of creation of an effective national communication system.

With America's overseas communication network safely under the aegis of a U.S. corporation, the Navy could return its attention to the advancing technology of radio. Most of the new developments centered about vacuum tubes. Improved understanding of space charge control, and better vacuum engineering, permitted tube manufacturers to produce ever-improving products, which the Navy was quick to use.

An early 3½-kw vacuum tube transmitter made for the Navy by the General Electric Company figured in the beginnings of radio broadcasting. On July 2, 1921, Jack Dempsey met Georges Carpentier in a heavyweight championship fight at Boyle's Forty Acres in Jersey City. RCA, determined to broadcast this great international event, created station WJY for the occasion. They borrowed the transmitter, which General Electric was about to deliver to the Navy, and installed it in the Lackawanna Railroad yard, with the aerial hung between two towers. The now-lengendary fight broadcast, which created stories that could fill many pages, helped launch the wave of enthusiasm that carried radio into the American home.

The Navy was of course doing other things with vacuum tubes. Researchers at the Naval Research Laboratory capitalized on the ability of the vacuum tube oscillator to generate far higher frequencies than had been possible theretofore. Despite existing theories that showed high frequencies (short waves) to be worthless for communication, NRL began exploring the properties of radio waves above two megacycles. Navy scientists showed that a 50-watt short wave transmitter gave communication with Panama even when the 250,000-watt long wave Annapolis transmitter could not get through, and they demonstrated the lightness and compactness of HF equipment by installing a mobile transmitter and receiver in the dirigible *Shenandoah* for her flight across the country and back in 1924. The following year the *Seattle* used HF to maintain daily contact with Washington while leading a fleet to Australia and New Zealand. Continuing propagation studies led to discovery of "skip distance" effects, and to basic understanding of propagation phenomena across the radio spectrum.

Much of the early short wave radio work at NRL was performed in a small hut mounted on top of a wooden antenna pole 80 feet high. On windy days the pole swayed dizzyingly, and from time to time eagles had to be discouraged from nesting in the hut; but despite these hazards, the U. S. Navy led the world in HF communication. Even higher frequencies were explored, too, as the Navy pioneered radio channels limited to line-of-sight ranges. Crystal control circuits for precise stabilization of these frequencies were developed through the ingenuity of the Navy communicators.

Radar was born on a Navy radio test range in the nineteen-twenties when A. H. Taylor and L. C. Young observed that passage of a ship through a high frequency field could be detected on their

receiver. Similar effects were noted with aircraft, so a study of the location of enemy vessels and aircraft was begun in 1932. Radar was at sea aboard the destroyer *Leary* by 1937, and aboard the battleships *Texas* and *New York* for battle maneuvers early in 1939. The story of radar in the Navy merits separate telling, and will not be carried further here.* It is worth noting, however, that the development of identification and communication systems to go with radar was just as important as radar itself. These developments culminated in the evolution of the Combat Information Center, (CIC), the heart and brain of World War II Navy fighting ships.**

The explosion of World War II brought a tremendous expansion of Navy work load in the radio communication area. The radar program was expanded; radio and radar jamming and anti-jamming were of necessity developed to a high degree; facilities for long and short range communication on, above, and below the sea were expanded and refined. All of these equipment programs required development of new tubes, new circuits, and new components. The Navy worked with the Army, the National Defense Research Council, and with industry to produce the apparatus essential to victory.

After the war, the Navy returned to the challenge of improving radio communication with a comprehensive study of propagation and interference. A whole new array of techniques was put to use: rockets shot into the upper ionosphere determined the pressure, temperature, and composition of regions never before explored. Detailed studies of radio emission from the sun, taking advantage of the solar eclipse, provided new insight into the effect of the sun on radio communication. Radio astronomy probed the skies beyond the sun to study the radio frontiers of space.

An important result of these studies was the discovery by Navy scientists of tropospheric scatter propagation. Other new modes of communication, such as transoceanic ducts for microwave signals, were sought.

Meanwhile, the tried-and-true techniques already established for communication to a world-wide fleet were being emphasized, too. A giant VLF radio transmitter was put in commission at Jim Creek, Washington, in 1953; and an even greater installation, capable of radiating over 2,000,000 watts, was opened at Cutler, Maine, in 1961. This newest colossus of the air waves was assigned the call letters NAA, made famous by the rhythmic dah-dit, dit-dah, dit-dah of Radio Arlington for so many years.

Is the Navy in the forefront of radio communication development today? The pages of the daily paper tell that the answer is "yes." Only last fall, when magnetic disturbances caused world-wide disruption of long-distance communication circuits, the Navy maintained its flow of traffic between Washington and Hawaii by bouncing 240-word-per-minute signals off the moon. And, as attested by its participation in project OZMA, the widely-discussed search for signals from beyond the solar system, the Navy will continue to lead the way into new developments in radio communication.

* The name "radar" was coined by Captain S. Tucker of BuShips.

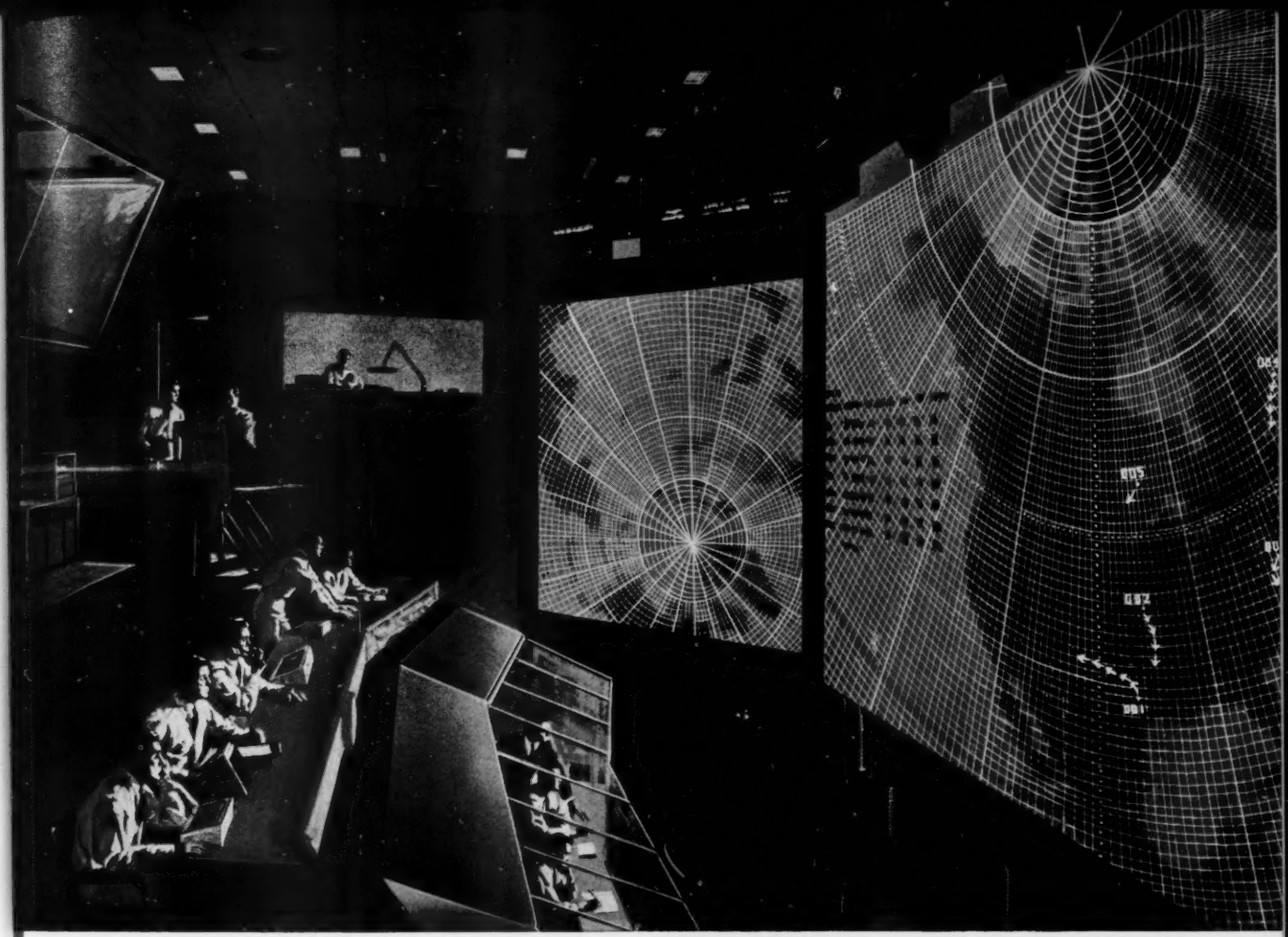
** The initials CIC were subject to wonderfully varied interpretations in the fleet. One example: "Criminy It's Crowded."

SECOND NUCLEAR FRIGATE

Early in June the House and Senate Armed Services Committees authorized another new nuclear-powered frigate for the U.S. Navy. This ship will cost about $130 million, have a displacement of around 8000 tons, and be powered by two pressurized water reactors. The first ship of this class, the ***Bainbridge***, is scheduled for sea trials next year.

Mechanical Engineering, August 1961

JOHNS-MANVILLE
JM
PRODUCTS
Materials for
MARINE SERVICE
Incombustible Joiner Materials • Acoustical Materials
Asbestos Ebony for Switch and Panel Boards • Structural Insulations
Boiler and Engine Room Insulations • Packings • Gaskets
Johns-Manville
Box 290, New York 16, N. Y.



NORAD ON THE ALERT

Inputs from BMEWS Provide Instantaneous Missile Data Direct to NORAD Headquarters

From our vast outer defense perimeter, over thousands of miles, to the nerve center of the North American Air Defense Command at Colorado Springs, the most advanced concept of data handling and checkout is being utilized in the BMEWS system. The stakes are high, for the purpose is defense of the North American Continent.

At BMEWS installations operated by USAF Air Defense Command, computers read out missile tracking data from giant radars. This information is simultaneously relayed to NORAD's Combat Operations Center.

The Radio Corporation of America is prime systems contractor for BMEWS. At the COC, RCA's Display Information Processor computing equipment automatically evaluates missile sightings, launch sites and target areas. By means of data processing and projection equipment installed by RCA and a team of other electronics manufacturers, the findings are displayed on huge, two-story high map-screens in coded color symbols, providing the NORAD battle staff with an electronic panorama of the North American and Eurasian land masses.

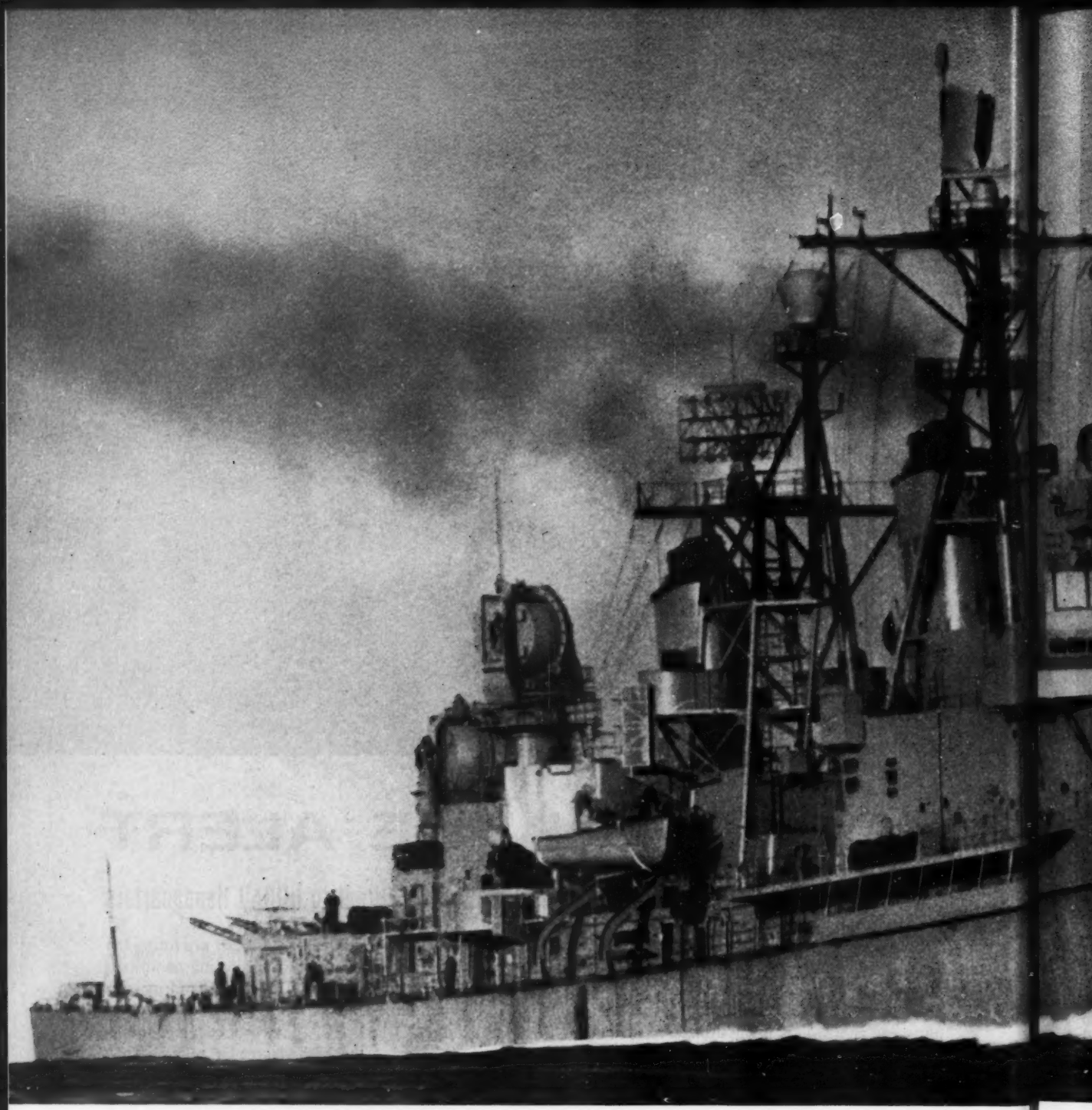
The handling of BMEWS inputs at NORAD is an example of how RCA data processing capabilities are assuring the high degree of reliability so vital to continental defense.

Out of the defense needs of today a new generation of RCA electronic data processing equipments has been born. For tomorrow's needs RCA offers one of the nation's foremost capabilities in research, design, development and production of data processing equipment for space and missile projects. For information on these and other new RCA scientific developments, write Dept. 434, Defense Electronic Products, Radio Corporation of America, Camden, N. J.

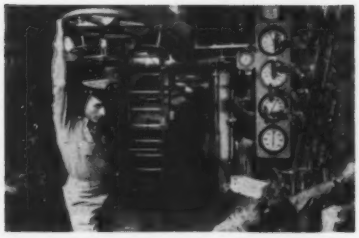
RCA®

The Most Trusted Name in Electronics

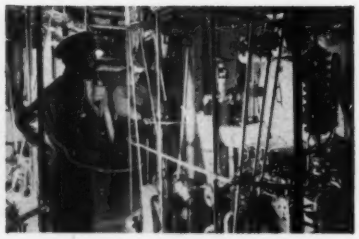
RADIO CORPORATION OF AMERICA



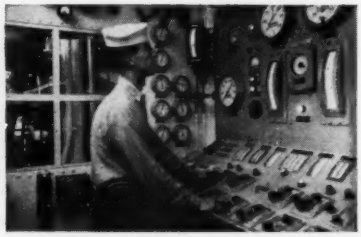
Four compact, high-output B&W boilers power the nation's



B&W boilers aboard the U.S.S. Dewey provide maximum power in minimum space.



View from second level shows easy access for inspection and maintenance.



Air-conditioned control room is equipped for automatic or remote-manual operation.

Photo by Bath Iron Works

first guided-missile frigate, U.S.S. Dewey

The U.S.S. Dewey (DLG 14), built at the Bath Iron Works, Bath, Maine, is the first of the Navy's new frigates designed to carry guided missiles. The U.S.S. Dewey is powered by four compact B&W two-drum integral-furnace boilers.

Providing maximum power in minimum space, the B&W boilers aboard the U.S.S. Dewey are designed for safety of operation, and easy access for inspection and maintenance.

These are the latest of many B&W marine boilers which have successfully met the Navy's exacting standards of performance and dependability.

By providing rapid response to steam demands, they contribute to the high acceleration, maneuverability and long-range striking power of the vessels that stand ready to safeguard the freedom of the seas.

We at Babcock & Wilcox take pride in our ability to supply dependable steam power for the greatest Navy in the world.

The Babcock & Wilcox Company, Boiler Division, 161 E. 42nd Street, New York 17, New York.

Babcock & Wilcox

FOR DEPENDABLE MARINE SERVICE

INSIST ON

'BUFFALO' PUMPS

MARINE MEN know that 'Buffalo' Pumps are completely dependable. Buffalo's uncompromising QUALITY standards insure efficient, economical, reliable performance. Maintenance is simplified by built-in ease-of-servicing. 'Buffalo' Pumps are used on every type of commercial and naval vessel. 'Buffalo' Pumps and Fans are 100% approved by the Maritime Administration.

QUIET, EFFICIENT 'BUFFALO' VERTICAL SINGLE & DOUBLE SUCTION MULTISTAGE PUMPS. Widely used where ultra-quiet operation is a must. Efficiency and dependability are unsurpassed. Two and four stage models in sizes to fit your needs. Suitable for clear water applications, hot or cold. Operate at pressures up to 1500 ft. head, at capacities from 20 to 900 GPM. Bulletin 980 gives full facts.

SPACE-SAVING 'BUFFALO' VERTICAL DOUBLE SUCTION PUMPS. These compact, efficient pumps save space in clear water service. Vertically split casing permits quick, easy access. Long-life features include renewable bronze wearing rings. Capacities to 14,000 GPM. Full details on request. For complete recommendations, write our Marine Department, 711 Woodward Bldg., Washington, D.C.

"Buffalo" PUMPS

MARINE DIVISION BUFFALO PUMPS

BUFFALO FORGE COMPANY

Buffalo, New York

Canada Pumps Ltd., Kitchener, Ontario

'Buffalo' Air Handling Equipment to move, heat, cool, dehumidify and clean air and other gases.

Squier Machinery to process sugar cane, coffee and rice. Special processing machinery for chemicals.

'Buffalo' Machine Tools to drill, punch, shear, bend, slit, notch and cope for production or plant maintenance.

'Buffalo' Centrifugal Pumps to handle most liquids and slurries under a variety of conditions.

UNDERSEA TECHNOLOGY NEEDS IN REVIEW

ACKNOWLEDGMENT

This article, by Don G. Groves of Defense Systems Department, General Electric Company, appeared in the July/August 1961 issue of "Undersea Technology" from which it is reprinted.

SUCCESS OF TOMORROW'S naval missions hinges on a drastic revision of the naval engineering technology state-of-the-art. More and more companies are trying to get into the act, but to date very little has been achieved in terms of a unified approach to solve the problems at hand. This is especially true when it comes to the many diversified yet related problems and needs in the undersea realm. Many of these needs fall within security limits and cannot be discussed. However, several specific marine and naval problems are not affected by security and it seems in order to briefly list and discuss some of them since they concern every engineer in the U.S. industry.

The list is intended to be representative rather than all-inclusive of recognized (by Navy and segments of industry) problems illustrating the challenging and encompassing engineer in the U.S. industry.

For materials and equipments that must operate in the under-ocean, exposed to sea growth, corrosion, pitting erosion, galvanic action, high pressure, etc., there is a need to:

Develop and improve high strength metals which are easily weldable, yet corrosion and pitting resistant; or develop economical coating or paint that will do the same thing.

Develop economical and effective materials and design techniques such as small-diameter, high-strength deep water mooring cables, underwater vehicles and robots, etc., for emplacement and reclamation of active and passive sonar system and other devices on the deep ocean floor.

Develop more economical and reliable welding (or other pressure-tight joining) techniques for thick metallic sections, including bi-metallic joints, for marine use. Special emphasis on deep diving submarine hulls where titanium and/or aluminum may replace steel in whole or in part. New materials concepts should be encouraged.

To aid and abet undersea search and kill, there is a need to:

Improve marine propulsion and auxiliaries bearing size, geometry, and lubrication in order to reduce noise generation and transmission. Special emphasis on thrust bearings for deep diving submarines subject to high hydrostatic pressure. Partial answer may be in use of seawater or steam to replace conventional oil lubricants. Throughout undersea technology more effort should be made to use the sea ambient environment to improve marine engineering.

Develop small-sized speed reducers of high torque capacity (as high as 65-to-1 reduction) producing minimum of noise in sonic and ultrasonic bands needed for torpedoes and thrust procedures and should be able to handle up to 1,000 shp. This technology might enable use of nuclear closed cycle gas turbines driving outboard propulsion system in some vessels.

Develop static high dc power electric generators (fuel cell or thermo-electric). Used with specific characteristics, static system would eliminate conversion, system would eliminate motor-generator sets (a noise source). Advance in fuel cell technology could result in "dead-quiet" submarine operation. Special emphasis on development of data leading to new techniques and hardware for attenuating or eliminating self noise,. machinery noise (mechanical couplings), cavitation noise, and flow noise in ships and underwater mechanisms and installations.

Create precise undersea surveying and navigation devices for reliable, extremely accurate determination of submerged vessel speed with respect to ocean bottom, an important factor in underwater missile launching. Also develop surface ship automatic pilot navigation.

Design of anti-submarine hydrofoil for high-speed surface operation combined with efficient underwater capabilities. This could in effect be a hydrofoil deep depth sonar platform utilizing optimum sonar conditions for search. After search vehicle would surface and proceed to next search area. Phenomenal weight-to-horsepower ratio possible with new power plants used with lightweight metal hull.

Accomplish breakthrough in generation, propagation, and reception of sound in ocean—or development of new devices—leading to a means of IFF for undersea surveillance. Chief problem today is to determine whether object detected by sonar is friendly ship, a whale, a school of fish, a decoy or other countermeasure, or an enemy submarine. All give sonar reflections. Limitations on transmission in water where temperature changes, coupled with fact that acoustic methods are slow and inexact point to greater emphasis in development of non-acoustic systems such as deep-sea optical maser.

In the field of marine power—main propulsion as well as secondary and auxiliary power—there is a need to:

Investigate the possibility of larger scale use of solid propellants for rocket underwater propulsion.

Design various imaginative devices to use and convert some of the oceans thermal and hydrostatic energy. Sea water contains uranium for fission-produced power and deuterium or heavy hydrogen for thermonuclear power. Another possibility is to obtain ac or dc power from shafts turning at 50,000 to 100,000 rpm. Also needed are systems to transduce main propulsion schemes to secondary and auxiliary power. Novel cryogenic refrigeration (apparatus and dewars built in to ship) might provide key to make certain energy-conversion modes possible. Some of these conversion models are:

Nuclear Energy to Thermal Energy via Fission or Fusion Reactor or Ionized Plasma Fission Reactor to Electrical Energy

Chemical Energy to Thermal Energy via Exothermic Chemical Reaction or Battery or Fuel Cell to Electrical Energy

Thermal Energy to Mechanical Energy via Diesel or Turbine

Thermal Energy to Electrical Energy via Thermal-Electric Devices

Mechanical Energy to Electrical Energy via generator

Electrical Energy to Acceleration of a Water Column and Propulsion via magnetohydrodynamic device

Electrical Energy for Electric motors for propulsion and Auxiliary Power

Thermal Energy to Acceleration of A Water Column and Propulsion via Hydrojet, or Rocket

Mechanical Energy to Acceleration of a Water column and propulsion via reduction gearing-propeller, etc.

In addition to the problems listed above there is also an urgent need for further development and improvement in the following specific marine engineering problem areas:

Nuclear propulsion reactor shielding.

Coating material to reduce frictional drag (especially for underwater craft).

Water resistant grease.

Underwater television and photography.

Image intensification enhancement devices.

New device to replace submarine periscopes.

Underwater countermeasure devices and techniques.

Surface and subsurface ship hull and propulsion design.

New communication systems through the air-sea interface.

Higher reliability, reduced maintenance, lower cost, and unattended systems program related to

the electronic, electrical, mechanical, etc. systems, of ships and crafts including aircraft.

Life sciences associated with human tolerance to unusual environments.

Anechoic engineering and application of viscoelastic materials.

Increased use of solid state devices in practically all marine vehicle design.

Hydrodynamic innovations—boundary layer control concepts.

Sensors in acoustic and non-acoustic devices not limited to ASW detection, for use on merchant ships, submarines, aircraft, etc.

Ambient sea noise research. Possible evolvement of detection techniques akin to those used in cosmic ray astronomy.

Natural science programs to study bird, fish, and animal features which might be adapted for man's use.

Inland Waterway icebreaker craft, possibly powered by water reactor and turbo-electric drive.

Redesign of special submarines, ships, and aircraft for oceanographic purposes.

More and better equipment for simulation of ocean environments.

Less expensive, more effective overhaul and repair methods, particularly for nuclear submarines and naval aircraft.

Small-size, broad-band sonar transducers.

Aside from the specific needs dealt with so far, the marine and naval engineering society is faced with a series of problems in general key areas with bearing on military as well as commercial interests. Again there is lack of a unified approach from industry's side, in spite of the benefits to be gained.

Establish an underwater commercial mining and salvaging technology to harvest some of the raw materials in the vast ocean. It is estimated that one square mile of ocean floor surface contains cobalt and manganese modules worth $0.5 million. Other commodities are oil, chemicals, and food. Emphasis is on development of inexpensive methods to bring these to the surface.

Develop underwater shipping and storage techniques as well as logistical underwater and mid-ocean support base systems.

Apply aircraft practices and vast pool of aerodynamic research t› ship design. Ship shape and speed have not changed significantly in the past 50 years. There is tangible, translatable similarity in the disciplines of: Hydrodynamics (hydrofoils) and aerodynamics (airfoils); meteorology and oceanology; sound energy through temperature gradients and electromagnetic energy transmission in the ionosphere, and many others. There is also the applicability of space technology to marine engineering (navigation, communication, weather prediction, and reconnaissance satellites.)

Increase hydrographic and oceanographic research. Despite much recent work in these fields results have not been applied or coordinated to utmost advantage. Perhaps this will be remedied through government's increased financial support of oceanographic research. Collected data is of no real value unless translated into devices, instructions, or practical rules.

Establish fundamental data for predicting such things as metallurgical performance with respect to fatigue, locked in stresses, creep, ductility, notch effects, etc. Also for possible reappraisal and working coordination of ideas related to mechanics, energy conversation, electronics, etc., all of which point toward new material and design developments. Marine design and engineering requires the skills and cooperation of many specialists. So far the individuals have generally worked in separate groups with little real interchange. Growing awareness of need for interaction between groups will benefit the entire marine engineering field.

BIBLIOGRAPHY

In the main this unclassified information has been gathered from several sources both oral and written. The written record consists largely of the following:

Navy Research and Development Problems—Dept. of Navy, Washington, D.C., *Underwater Engineering Vol.* 1, Number 3, *Military Marketing Data Committee* Report of Electronic Industries Assoc.

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

COMMANDER BERNARD M. KASSELL, USN (RETIRED)

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

THE AUTHOR

enlisted in the Navy in 1931, and served continuously until his retirement. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institution. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He was recently stationed in Casablanca, Morocco as Commanding Officer, Military Sea Transport Service and retired after 29 years of active duty. His last duty station was in the Office of the Chief of Naval Operations. Is now engaged in consulting and independent research on Soviet affairs.

NORTHERN SEA ROUTE OPERATIONS

At the end of the first 80 days of Arctic operations conditions, initially difficult because of very heavy ice packs along the routes, particularly in the Western sector, had improved somewhat so that ships could move in both directions.

According to L. V. Rozanov, Senior Engineer in the Arctic Maritime Operations Division of the Main Administration for the Northern Sea Route, caravans, with the aid of all available icebreakers have been moving to Tiksi and Pevek and to the Kolyima and Khatanga rivers. By the end of August the season was in full swing, with deliveries under way to the shore and island polar stations along the Kara Sea. Many of the ships have been used over this route for quite some years now and, with personnel experienced in the operations in ice, are able to make their deliveries quickly and with minimum damage.

Not only Soviet ships, but ships under the flags of Finland, West Germany, the Lebanon, Norway, Great Britain and Sweden have visited the port of Igarka to load, usually, timber.

In addition to these merchant ship movements, a large group of newly built ships moved over the route for destination on the Siberian rivers. Some had arrived on the Ob and Yenisey, others were under convoy and had reached Dikson, stopping there to await improvement in the ice conditions before moving on to the Lena River.

While all movements over the Western sector appear to have required the use of icebreakers, conditions on the Eastern sector were so much better that icebreakers were needed only when the northwester winds pushed the pack close to the coast. Virtually all polar stations, farms, trading posts, schools and hospitals along the Chukotsk coast had been supplied by the end of August, with many of the ships engaged having made several trips by that time.

As in past years, the ships were assisted by Polar Aviation of the Civil Air Fleet. Pilots, flying helicopters as well as fixed wing aircraft, did the ice survey work needed to select routes through the pack ice.

Arkhangelsk, Vladivostok and Nakhodka were

said to be completing their work for the season, loading the last ships assigned to runs into Arctic waters.

Curiously, not a single mention of the use of the atomic icebreaker *Lenin* had been noted at press time.

DRY CARGO CARRIER *Poltava*

At mid-year the I. I. Nosenko Shipyard in Nikolayev, on the Black Sea, was completing the construction of the first of a new class of cargo ship, *Poltava,* designed to carry such diverse types of cargo as loose timber, long-length cargoes, containers, trailers loaded vertically, and general cargo.

The ship, a motor vessel, was planned to class in the Register of the USSR, LR4/1S and is a full scantling, two-decked ship with the machinery spaces, living and working spaces, as well as a refrigerator compartment for carrying perishables, aft.

The main elements, as well as some of the ship's characteristics, include:

Length, overall, feet	510
Length between perpendiculars, feet	459
Beam, greatest, feet	67.5
Height of side, amidship, feet	40.3
Height of tweendeck, feet	11.5
Draft, normal load, feet	25.3
Draft to Plimsoll mark, feet	29.5
Displacement at Plimsoll mark draft, tons	18400
Displacement at draft of 25.3 feet (cargo capacity 8000 tons)	15320
Deadweight (depending on comparative cube of cargo), tons	9500-12540
Cargo carrying capacity, cubic feet (crated cargo)	564000
Cargo carrying capacity, cubic feet (bulk cargo)	666000
Main propulsion installation, ehp	8750
Design speed, draft 25.3 feet, knots	17
Design speed, maximum draft, knots	16.5
Cruising radius, miles	10000
Crew	41
Passengers	9

Some of the philosophy which went into the planning of the ship is worthy of examination, particularly because, as has been pointed out in previous articles, much time is lost in Soviet ports in the conduct of cargo operations.

Planners equated the factors involved in faster ships versus this long delay encountered in ports and decided that the shorter voyage times resulting from faster ships not only disappeared in the face of longer delays in port but even, because of higher initial costs, resulted in overall losses in operations. It was decided, therefore, to look into the matter of cargo handling operations and see what could be done in this fertile area.

From the Soviet viewpoint cargo operations can be speeded up by packaging cargo, using containers or trailers (although use of trailers calls for ships of special design and construction and these types of ships have not, in the past, always proven economically effective), creating conditions such that in the course of loading, or unloading, it is not necessary to handle cargo twice in any one hold.

A second approach is to make deck openings as large as possible. Ships with beams up to 52 to 54 feet can accomodate hatch openings of 33 to 36 feet, although a certain amount of manual labor is required because pockets along the outboard sides remain. Where the beam reaches a figure of 65 and more feet (the case with *Poltava*) this approach would result in hatch openings so large that they would be a disadvantage and difficult to handle.

Thus, the approach taken was to design the hatch openings in pairs athwartship. At the same time it was decided that deep tanks, used for ballast purposes, served little purpose in the handling of cargoes and that, in order to reduce the weight of metal in the hull it was desirable to set the engine room and superstructure in the stern, to install wing tanks as a sort of double wing amidships, to install a diametral bulkhead and to use cranes for cargo handling.

As a result of this reasoning the design incorporates three pairs of hatches which are 44.7 feet long, one pair 79 feet long and one central hatch for hold No. 1 which is 27.5 feet long. Hatch widths are on the order of 20 feet, approximately that of the World War II *Liberty* ships.

Economically, estimates were based on the use of ships of this class on lines from 2,000 to 10,000 miles in length, the ships carrying general cargo. If the time spent on cargo operations can be reduced by up to one-half the present, and if labor productivity can be stepped up 15-30 percent among the crew, transportation costs can be cut, the capital investment can be cut anywhere from 10 to 50 percent and the total effect of all this can be improved economic indices on the order of 25 to 50 percent. But even this broad range of estimation depends on "careful organization of operations."

As now planned the ship will carry a slow-speed diesel Mark 7DKRN74/160, rated at 8750 ehp at 115 rpm, directly coupled to a single, four-bladed propeller 18.7 feet in diameter. Supercharging is accomplished by two gas turbines, sucking air directly out of the engine room. In addition the engine is fitted with an emergency, electrically driven centrifugal blower so that the engine can be operated at reduced power. Cooling is by fresh water in a closed system.

The ship's service generators are located on a platform in the engine room. The installation is made up of three diesel-generators type DG-300, alternating current 50 cycles at 400 volts. Each generator is rated at 300 kw while the engine runs at 500 rpm.

RIVER ICEBREAKERS

In 1950 the "Krasnoye Sormovo" Shipyard, in Gorkiy on the Volga River, built the first two river icebreakers, *Don* and *Volga,* to be placed in service in the post war years. (See the "Journal," November 1957, p. 726). These were 1800 hp units, of diesel-

electric propulsion, fitted with two propellers. In 1957 the Baltic Shipyard *imeni* Ordzhonikidzye built a new series of the same type, including *Kuban, Dnepr, Oka, Terek,* and others. In the winter time the ships are used as icebreakers, in the summer time as tugs.

As was pointed out in the 1957 article, operating experience with the first two units revealed certain faults. These faults now appear to have been compounded by faulty propeller design as well. Initially the propellers had been shrouded, but the first winter's operations in ice resulted in sufficient damage to the shrouds as to make removal desirable. Further operation merely resulted in damage to the propellers themselves, however, with the end result the replacement of the original propellers with sturdier ones made of steel. Later on the propellers fitted to *Don* were increased in diameter from 6.9 to 7.7 feet and, it is claimed, the icebreaker operated for many years on various sections of the Volga with no further damage. Careful design also enabled the breaker to retain its former pulling power. Originally, when the shroud was fitted, the tests made during dock trials revealed a pull of 16.3 tons at a developed 1105 kilowatts (a dynamometer having been used to compute the results) whereas, without the shroud the pull, at 1067 kilowatts, proved to be 15.9 tons.

The later units were fitted with propellers with a disc relationship A/A_d of 0.55. These propellers were installed in shrouds made of sheet steel of increased rigidity and ice protection for the complex was provided in the form of baffles made of steel beams of elliptical section installed forward of the shrouding. *Oka,* however, failed to meet trial specifications as to pulling power, with the result that *Kuban* received a set of propellers with a disc relationship A/A_d of 0.75 while the shrouding inlets of *Dnepr* were increased in size from 74″ to 76.5″. *Terek* incorporated both alterations.

Trials, conducted with *Terek,* were interesting. In ice thicknesses ranging from 10 to 12 inches, and with as much as 6 inches of snow cover, the number of propeller turns remained stable from the moment of impact with the ice until the breaker had come to a complete stop, anywhere from one to one and one-half ship lengths into the pack. When the trials were moved into areas where the thickness was somewhat less, 8 to 11 inches, but the operating time was extended because the breaker did not become completely stopped, turns dropped off considerably and overloading of the main motors was encountered. Part of the trouble resulted from impacting of the crushed ice in the shrouding so that every 5 to 7 minutes it became necessary to reverse the motors, freeing the shrouding of the ice. Since neither *Don* nor *Volga* had shrouding and protective baffles this particular trouble had not occurred.

Another problem arose in the course of summertime operations. Although a gain of almost one ton was obtained in pull, during trials, in actual practise it was found that as towing speed increased this advantage disappeared and, when operating without a tow, the breakers fitted with shrouds made about one mile per hour less than those not so equipped. In fact, at maximum turns, on the order of 270 rpm, the effectiveness of the propeller installation of *Terek* dropped 10 to 15 percent, because of the effect of cavitation. The engineers now feel that the selection of the elements entering into the propeller installation, as well as the design of the propeller itself, was not a good one and that, as a result of the operations thus far conducted, as well as trials under actual operating conditions, icebreaker-tugs of this class should not be fitted with shrouds.

SHAFT GENERATORS

In recent years the use of shaft generators has come into practise on an ever widening scale in the Soviet Merchant Marine. Both AC and DC generators have been adopted from tests indicating that, for the various classes of ships tested, underway requirements for electric power rarely are in excess of 10 percent of main engine power.

This being so, the idea has been attractive to Soviet naval architects and engineers because, once the ship is underway and steaming steady, the installed steam or diesel propelled generating sets can be secured. Too, given proper coupling, transmission of engine power to the generators is said to be on the order of 90 to 95 percent efficient.

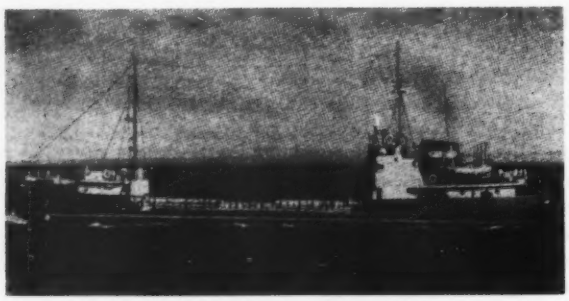
DC generator voltage outputs are maintained constant, in the face of variable engine revolutions, by regulation of the current in the exciter winding. AC alternator control is accomplished either by maintaining the frequency constant for variations in turns, or by varying the frequency. The former, calling as it does, for additional equipment, does not come very highly recommended.

Calculations made on ten ships suggest that the economy involved is on the order of 33 percent. These same tests reported that the ships, while underway, generated almost one million kwh of electricity per year and that the fuel to run the stations to provide this power cost 10,000 rubles for diesel, and 2 to 3 times more for steam propelled installations.

Conclusions are that it is technically possible, and even desirable, to install shaft generators on ships of various classes; that with shaft generators a considerable reduction in costs of operation can be expected, not only from reduced fuel costs, but from lesser expenditures on repairs to the installed engines and generators; that with the installation of shaft generators servicing is simplified and real possibilities are provided for automation of shipboard electrical plants.

SEAGOING SCOW

Late in 1960 a self-propelled, seagoing scow, or hopper barge, *Chernomorskaya-1,* (Black Sea-1) was placed in service, the first of a class designed to



Seagoing scow *Chernomorskaya-1*

operate with dredgers in the channels in the Baltic, Black, Azov, Caspian and White seas.

Built to class LR4/1S (Scow) of the Register of the USSR, the ship has been strengthened for ice operations and will carry the dredged materials for dumping at sea for distances up to 100 miles from port.

Main elements include:

Length overall, feet	180
Beam, greatest, feet	34
Height of side, feet	14
Displacement, full, tons	1330
Draft, mean, full displacement, feet	11.4
Capacity of holds, cubic feet	17650
Crew	16

Hull and superstructure are of steel, all welded. Hatch mechanisms are electrically driven, rather than of the hydraulically operated type and vibrators, as well as special water washing systems, have been installed in the hoppers to make dumping and cleaning simpler.

Propulsion is provided by two, non-reversible diesel engines Mark 6Ch-p25/34, rated at 300 hp each at 500 rpm. A reverse-reduction gear provides for transmission.

All auxiliary machinery is electrically driven from two AC diesel-alternators, rated at 50 kw, 230 volts.

Controls are centralized in the wheel house and the rudder installation has proven adequate both ahead and astern, except when engines are stopped and the ship has stern way on, in which case control is inadequate.

The design came out of Gorkiy and members of the Scientific-Technical Society of the Shipbuilding Industry participated in the incorporation of certain of the features new to this type of ship.

TECHNICAL PROGRESS IN SHIPBUILDING FOR THE FISHING INDUSTRY

Added impetus has been given to development of the branch of shipbuilding dealing with the construction, and design, of commercial fishing vessels by the establishment, within the Scientific-Technical Society for the Food Industry, of a section to deal solely with the fishing industry. Workers in the fishing and in the shipbuilding industries got together in Leningrad earlier this year to discuss the question of building modern commercial ships as the basis for meeting the task of increasing the fish catch.

There is little doubt that over the past five years or so the number of ships in the commercial fishing fleet has increased tremendously. Soviet claims are that the number of self-propelled ships in this fleet, as of 1960, had increased 263 percent over the 1955 figure. Included in the additions, and all reported in these pages in previous articles, are such large freezer trawlers as the *Mayakovskiy* and *Pushkin* classes, a large group of whaler catcher ships, medium trawlers of the *Okean* and *SRT-400* classes, the whaler bases *Sovetskaya Ukraina* and *Yuriy Dolgorukiy* and the floating cannery *Andrey Zakharov*.

The conference noted the tendency towards processing the fish at the fishing grounds, right on board the fishing craft, with delivery to port at a later time but with the quality of the catch better and the work of the shore canneries made easier, and thus more economical.

Accordingly, further additions to the fleet should be, primarily, large, ocean going types, with unlimited range and duration. A program such as this would involve provision of modern navigation equipment, long range communications installations, high levels of automation of search procedures, mechanization of the fishing processes, complex mechanization and automation of the processing of the catch and mechanization of the freezing processes using fast-freezing equipment.

The following main types of ships were recommended for addition to the commercial fishing fleet:

(1) large freezer, trawlers with ability and equipment to operate at long ranges from home ports, and including modernization of the *Mayakovskiy* class trawler, which also bears the designation BMRT (for Large Freezer Fishing Trawler), taking into account the technical achievements and the operating experience gained from active ships of this class which were destined for independent operations in the North Atlantic and the northern part of the Pacific Ocean; new fish factory trawlers bearing the designation BMTR with increased cargo capacity, displacing over 6000 tons, equipped with standard installations suitable for extended operations in tropical waters; new sardine and fish canning factory trawlers, designated BSTR, to process and can sardines in the regions of the South Atlantic which will displace over 6000 tons;

(2) freezer trawlers using stern trawls (RTM) for operations in the tropical waters of the South Atlantic;

(3) medium sized freezer trawlers (SRTM) for operations in the North Atlantic equipped to process the fish into a salable product;

(4) large tuna fishers for independent operations in the equatorial waters of the Pacific, as well as the Atlantic Ocean;

(5) small tuna boats for use with base ships sent out on expeditions in the tropical waters of the South Atlantic and the Pacific oceans;

(6) tuna base ships to care for the type in (5);

(7) scientific survey ships for carrying out the complex fishing research to be done in distant regions of the world's oceans;

(8) large base-factory ships for trapping and processing seals, and other types, in the northern seas;

(9) base ships for trapping operations in the Caspian Sea;

(10) fishing vessels for catching sprats in the Caspian Sea and processing them into fish meal;

(11) large factory ships for use as floating bases for the processing of fish meal in the Far East;

(12) floating fish canneries for processing the raw fish into canned goods;

(13) refrigerator-transports for carrying frozen, chilled and lightly salted fish products;

(14) commercial refrigerator-factory ships, for use as floating bases, and able to receive sardines and bottom fish from the fishing vessels, convert them in to ready to use products and to act as supply ships for the fishing vesels, providing them with fuel, water, food and industrial equipment;

(15) floating bases for processing water plant life;

(16) ships for close-in fishing purposes for use in various basins and equipped with refrigerated holds (trawler-seiners).

Also under discussion was a program for outfitting ships now under construction with the latest equipment so that fish can be processed immediately after being caught, thus preserving the flavor and quality of the species. The widespread development of quick freezing methods was noted and, so far as the Soviet Union is concerned, the conference urged the participating scientific groups to step up the tempo of development of this method and adapt the use of automation and standardized types of installations to its use.

REFRIGERATOR-TRANSPORT SHIP

Last spring a group of shipbuilders met in Nikolayev to discuss certain features of a new refrigerator-transport ship which is to be put into serial production at an undisclosed time. The refrigerator installation is to use ammonia and freezing of fish will take place in holds capable of carrying 180 tons. The ship will displace 650 tons, will have a speed of 10 knots and will carry a crew of 30.

Operating areas will include the Black, Caspian, Azov and Aral seas, lakes Baykal, Balkhash and others, as well as the Ob, Yenisey and Lena rivers.

BANANA BOATS

West Germany has been building a series of motorships for use in the banana trade which can also carry chill and frozen cargo. The first of the class for the Soviet Union was *Aragvi*, reported as in service in 1960, built to class in the German Lloyds GL-100A4DAZ and ice strengthened to class L in the Register of the USSR. Main elements and characteristics of the class include:

Length overall, feet	395
Length between perpendiculars, feet	358
Beam, feet	54
Height to main deck, feet	28
Draft, loaded, feet	
designed	18
maximum	23
Cargo capacity, tons	
at draft of 18′	2220
at draft of 23′	4410
Main propulsion, ehp	7250
Speed, knots	18
Crew	54

The main engine is the MAN type K8Z-70/120, rated at 7250 hp at 130 rpm.

Cargo is carried in four holds, each covered with an individual, hydraulically operated, folding hatch cover. Elevators are installed in each hold to assist in loading and unloading the bananas. The elevators are loaded through cargo ports installed in the sides of each of the decks. Each hold has two chilling groups, each of which can be independently controlled. The freezer installation operates on Freon 12.

PROJECT 765 UNSATISFACTORY

Towards the end of 1959 the Northwestern Steamship Line received eight new cargo motorships built in the "Leninskaya Kuznitsa" Shipyard in Kiev, on the Dnepr River. The Central Planning and Design Bureau designated the project as Number 765 and all eight were assigned to the Leningrad Repair-Operations Base for administrative and maintenance control.

In the 1960 season the new ships were operated on the run between Leningrad and Cherepovets carrying grain. As a result of the season's operations serious doubts have arisen as to the advisability of further use of the class under the conditions which exist in the northwestern river basin. Let's take a look at the technical features:

Length, feet	213
Beam, feet	30
Height, without masts, feet	31.5
Cargo capacity, tons	
for Class O (Lake) and draft of 6′	600
for Class R (River) and draft of 8′	900
Main propulsion (2 x 3D6S), hp	300
Speed, still water, 600 tons cargo, mph	10

Propellers fitted in directional shrouds. Ships destined for carrying dry cargoes on the Dnepr and Volga rivers and on the reservoirs.

Surprisingly, the design is such that, even without the masts the ships had trouble getting under many of the bridges found in the operating area assigned. It is indicated that a height, presumably without masts, of 25 feet, rather than over 31 feet, is desirable. Just having to wait for bridges added

two days of operating time to a voyage! Among other faults were such items as too light construction of the shrouding around the propellers, poor maneuverability on shallow sections and in narrow fairways, rapid wearing of bearings, propeller damage resulting in surprisingly high repair costs over extended periods.

Perhaps the overhaul figures tell the story better than words. The following table was compiled from data obtained by dispatchers and the Base's Planning Division:

Ship No.	Total Operating Time, days	Time in Repair, days	Time in Repair, %	Repair Cost, 1000 rubles	Plan Fulfillment, %
ST6-860	172	54	31.4	2.23	53.3
ST6-861	157	36	22.9	4.98	64.2
ST6-862	177	47	26.5	3.05	73.0
ST6-863	177	29	16.4	1.43	56.3
ST6-864	170	44	26.0	3.40	79.0
ST6-865	184	48	26.0	3.90	72.2
ST6-866	195	30	15.4	3.39	71.0
ST6-867	185	23	12.4	1.97	87.6

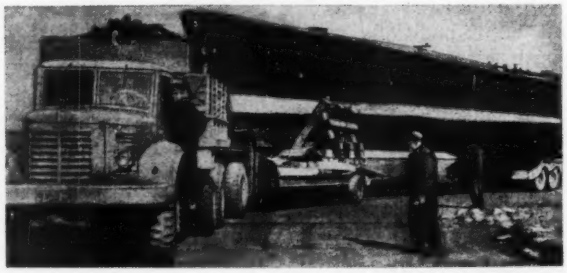
The sail area of the class is said to be so high that it was impossible, in strong winds, to operate the ships empty. When empty the class draws a little over four feet aft, but only slightly more than two feet forward. When it is recognized that ships operating on the grain lines are empty half the time, the problem is even more complicated, particularly when it is noted that the "Matrosov" anchor installed is too light to hold in the harbors. A whole host of other problems involving less speed than originally planned, a turning circle more than double that planned, and similar difficulties lead one to believe that the design was developed without adequate supervision or checking.

And it is suprising to find that, despite a hull plate so thin that holes have been punched in it by bolts used to secure the fenders in locks, deliveries have continued. The total in mid 1961 had reached 15, to be increased to 25 by the end of this operating season.

OVERLAND MOVEMENTS

This past season passenger traffic opened on one of the newly formed reservoirs, Mozhaysk, over a 25-mile stretch. The ships used were sent from the Moscow Shipbuilding and Ship Repair Yard and were the lake-type *Moskvich*. The *Moskvich* is a standard passenger type, but the delivery method was somewhat unusual (see cut).

In Moscow's Southern Port a 50-ton crane was used to load the individual hull into a special cradle, shown in the cut, and the truck then hauled the load to the reservoir where the ship's assembly was completed, presumably afloat. The length of the cradle is almost 100 feet and the hull's weight is 33 tons.



Transporting the hull of a lake-type *Moskvich* passenger ship

BOILER CLEANING

On 1 December 1960 new norms were introduced in the Soviet merchant marine to delineate the periods of time boilers might be steamed before cleaning. The norms have been broken down into two categories: periodic, and long term. Soviet engineers have been advised that the period of time elapsing between boiler cleanings is dependent to a large measure on the quality of technical operation and attention given to the main propulsion installation as a whole and includes elimination of leaks, keeping salt water out of the condenser, as well as oil out of the boilers, and treating the feed water properly.

The new norms were arrived at after operational records from the companies for the years 1958-1960 were studied. The records included boiler inspection reports, monthly and annual inspection reports and summaries, engine room and fire room logs and results of inspections made on a number of class ships. The results of the study indicated that the period of time between boiler cleanings had increased considerably, the result of improved operations of steam propelled plants, modernization of water treatment and feeding which eliminated the need to use boiler compound, and improvement in methods for keeping oil out of the boilers.

Perhaps more important than all the above, or perhaps because of all these reasons, boiler casualties have dropped and the Register of the USSR has data to indicate that failures because of impurities in the boilers dropped considerably between 1957 and 1959.

As a result of all this the following norms for periodic boiler cleaning, on board both serial and non-serial ships, are in force:

Type Boiler	Period between boiler cleanings, hours	
	When feed water is treated prior to entering boiler	When feed water is not treated prior to entering boiler
Fire tube	6000	4000
Combination	5000	3000
Water tube		
used with reciprocating engines	5000	3000
used with turbine engines	7000	—

The time spent by boiler cleaning crews, not necessarily ship's force, depends on the type of boiler, its design and size, but should not exceed the times set forth in the table:

Type Boiler	Time to clean one boiler, days
Fire tube	4
Water tube	4
Combination	5

The only deviation from the above has been permitted ships of the *Donbass* class, a Polish-built class, the lead ship of which was delivered in 1952, which, because of some design peculiarities, can have 7 days per boiler for cleaning purposes.

The new norms, if they can be met, will enable boiler cleaning time to drop some 50 per cent and further, assuming certain new, progressive measures take root, to the point where boiler cleanings will only be necessary during annual overhaul periods.

DRY CARGO AND TANKER TYPES

Present day planning for the future Soviet merchant marine is indicative of what can be expected, not only in Soviet building programs, but in orders placed abroad.

Three types of cargo carriers suggest themselves for future use: 3000-4000, 6000-7000 and 11000-13-000 tons. As distinguished from present day types, these new ships will feature means for rapid cargo operations, both of ordinary cargo and cargo in packages and in containers.

Instead of the 10,000 ton tanker of the *Kazbek*-class, we can expect to see the Hammer and Sickle flying over 18000-20000 tonners which will be able to carry not only petroleum, but products as well. A larger class, of 26,000 tons, can be expected and, as ports are built and rebuilt, so that depths in approach channels and alongside docks can accommodate them, 45000-50000 tonners can be expected.

Experimental units to carry compressed gases, manufactured and semi-manufactured chemical products, and other, similar cargoes, are anticipated.

While all this planning is going on, the repair yards are complaining that the designers pay no attention to them, that ships are designed and built without regard for the fact that repairs ultimately become necessary. One specific example. On the *Akmolinsk* class of refrigerator it is necessary to cut out the ventilation hatch over the engine room in order to remove a Mark 3D100 engine, the actual opening being too small to accommodate the engine. On the *Kurgan* class supplementary operations cost 50,000 rubles, added to ordinary repair costs.

DREDGERS FOR THE CASPIAN SEA

The falling water level on the Caspian Sea is an old problem and about the only solution, at the present time, is dredging out the channels to ports as the level recedes. It is, therefore, hardly surprising to find that the dredging fleet on the Caspian has been steadily increased. In 1958 the East German-built bucket dredger *Turali,* a 600-hp unit, capable of handling 525 cubic yards of material per hour, arrived on the Caspian. It was designed to work to a depth of 40 feet, but by changing the framing this depth can be increased to 47 feet.

In that same year the non self-propelled cutter head dredge *Beloye Morye* arrived on the Caspian ready to operate. This dredge was rated as handling 655 cubic yards per hour, with a maximum dredging depth of 40 feet.

Diesel tugs, such as *Uzboy* and *Nebit-Dag,* have been assigned to handle the scows capable of loading 260 cubic yards, while motor cutters of 150-hp of the *RB* (Roadstead Tug) type have been assigned to service the dredger caravans and the afloat installations.

New barracks ships, built in Bulgaria, have comfortable one and multi-place cabins and modern conveniences for the caravan crews.

Early arrival of three new diesel-electric, self-propelled dredgers is expected. These suction dredgers, designed by the Central Planning and Design Bureau No. 8, will have a capacity of some 2000 cubic yards per hour, three times the productivity of such old line suction dredgers as *Babushkin, Lenkoran* and *Beloye Morye,* the new unit. These new dredges will be able to operate between ports on their own power, which will be a rated 3000 hp, as opposed to but 600 hp for the older dredgers. The cutter head drive is 600 hp for the modern units, as opposed to a 250 hp drive in the smaller ones.

At about the same time that the new dredges are scheduled to arrive, arrival of self-propelled scows from Odessa is also expected. It may be supposed that the *Chernomorskaya-1,* discussed earlier, is the class which will find use on the Caspian.

GAS TURBINE CONSTRUCTION

The Kirov Works, Leningrad, was reported as having under construction, at mid year, the first gas turbine unit to be built in the Soviet Union for use in the Soviet merchant marine. In typical Soviet fashion the assembly, designated GTU-20, is said to have no equal in the world.

Many of the parts and assemblies are being manufactured by other Leningrad organizations, such as the Bolshevik Works, the Baltic and Armiralty shipyards. Trials had been pledged for the opening of the XXII Congress of the Communist Party, October 17.

TRIALS OF THE ICEBREAKER *Moskva*

Moskva is the 9200 GRT icebreaker, first of two, built in Finland for the Soviet Union. During the 1960 season scientists from the Arctic and Antarctic Institute and other organizations tested the main and auxiliary equipment installed.

The diesel-electric propulsion installation in the ship consists of eight diesel engines, rated at 3250 hp each, rigidly coupled to generators bearing the designation GM434.80-8 providing power for the three shaft main drive motors. The rated output of each generator is 2150 kw, or 2925 hp.

The total power of the diesel installation is 26,000 hp, with 22,000 delivered to the shafts. Underway in the ice the propeller turns were 115 rpm.

The main diesels are the Wartsila-Sulzer type 9MH-61, of nine cylinders, non-reversible, with a constant speed of 330 rpm. Trials were conducted, however, at speed settings of 260, 300 and 330 rpm.

Noise level measurements were also conducted and it was found in no case did levels exceed those designated as normal in any of the living compartments, except for two 8-man cabins located over the outboard propellers.

CASPIAN SEA OPERATIONS

Changes have taken place in the makeup of the fleet operating on the Caspian Sea, both in dry cargo and tanker types. As a result, some of the older tankers, such as *General Azi Aslanov*, have been assigned to permanent operations and, as an indication of traffic conditions, in 1960 made 303 trips to the offshore drillings known as Neftyanyiye Kamni (Oil Rocks) and brought over 3 million tons of petroleum back to Baku.

The addition of shallow draft tankers, the *Oleg Koshevoy*-class, has resulted in a continuing reduction in transshipment operations in the Astrakhan Roads. In 1959, for example but 490,000 tons of oil moved into Astrakhan without transshipment. in 1960 the shipments totalled 1,657,000 tons. The 1961 anticipated figure is on the order of 2,000,000 tons.

This class of tanker is being automated by the installation of such equipments as gyro pilots, electronic equipment to provide continuous coordinates of position, direction finders and radar. Cargo handling as well as certain of the engine room functions will be automated. Experimental propellers are planned for *Fedya Gubanov*, one of the Bulgarian-built shallow draft tanker types.

Shamkhor, the dry cargo version of the tanker, made the first experimental voyage from Krasnovodsk all the way to Kineshma on the Volga above Gorkiy with 2100 tons of cotton, returning to Baku with a cargo of sawn lumber.

PORT TUG WITH KORT PROPELLERS

The Technical Administration of the Ministry for the Maritime Fleet has released the following characteristics for the first of a series of all-welded steel port tugs fitted with two Kort propellers in the bow:

Length overall, feet	80
Beam, feet	23.6
Height of side, feet	9.5
Draft, feet	6.5
Displacement, tons	174
Towing power at 5 knots, tons	5.5

The hull is framed in the transverse system and is divided up into 7 watertight compartments. Bow and stern extremities are ice strengthened. The main engines are two in number and are 4-cycle, 6-cylinder, non-reversible, single acting diesels Mark 6Ch25/34 manufactured by the Pervomaysk Works *imeni* 25 Oktyabrya. This mark engine is rated at 300-hp at 500-rpm and a maximum of 330-hp at 513-rpm.

The propellers are DKK 20/5 with horizontal drive shafts, with the lead shaft rotating at 500-rpm. Diameter along the axis of the blading is 79 inches, the length of the working part of the blade is 47 inches. The propellers have five blades. The dry weight of each propeller unit is close to 3600 pounds. The reduction gearing is a conical gear with a transmission ratio of 1:5.8 and control of both propellers is from the wheelhouse by remote control. Maximum speed is 9 knots.

WATER BARGE AND WATER-WASHING STATION

Two non self-propelled scows are reported to have been converted into water carrier and water-washing stations. Principle elements of the barges include:

Length, feet	131
Beam, feet	42
Height of side, feet	8.5
Draft, feet	6
Displacement, tons	555
Cargo capacity, tons	384

The machinery installed includes two diesel generators of 25 kw each. The engine is a 4ChA 10.5/13 rated at 40 hp, a piston cargo pump driven by an electric motor, a bilge pump and an auxiliary equipment. Total water tank capacity is 325 tons.

DRY DOCK TRANSFER

Late in June a caravan made up of the large tanker *Pekin*, the icebreaker *Sibiryakov*, and the salvage tugs *Atlant*, *Poseydon* and *Argus* departed from Kronshtadt, on the Baltic, for the Black Sea with *Pekin* towing a floating steel dry dock capable of lifting 60,000 tons. Dimensions of the dock are given as 820 x 197 feet. *Pekin* was selected as the towing medium because of her 19,000 hp propulsion plant, her fuel and water capacity and ability to ballast down for better stability in the event of rough water. Original plans called for 48 days to complete the 5,233 mile voyage.

HYDROFOIL *Sputnik*

Early in July the Krasnoye Sormovo Shipyard in Gorkiy, on the Volga River, announced the launching of the latest in a series of hydrofoils building for passenger use on Soviet rivers. *Sputnik*, as the latest addition is called, will be able to carry 300 passengers at speeds up to 50 miles per hour.

TRAINING PROGRAM FOR FUTURE SEAMEN

Recent changes in the laws concerning public education in the Soviet Union have resulted in corresponding changes having been made in the manner in which the training of cadres for both the merchant marine, and the river fleet, takes place.

Basic training in middle and higher institutions of learning now is a combination of theoretical study and practical work. In fact, the whole system of preparing cadres has been completely redesigned, with the greatest changes occurring in the phase dealing with work afloat which has now become a direct link between the school and production activities.

This year, for the first time, hundreds of students. after completing basic, general technical and special courses in maritime disciplines were shipped out on vessels assigned to the Black Sea, Baltic, Latvian and other companies. The duration of the assignment is a year, during which time the student will work in his particular specialty and will study by correspondence. Students in engineering specialties, for example, were shipped out as motorists and machinists first and second class. Future electricians and radio operators, before going on board ships, will be qualified as shipboard electricians, radio operators second class and radio telegraphists.

In the year at sea the student must maintain close communications with his school and prior to his having left school he was briefed in the best methods of independent study and the manner in which he was to complete his assignments.

Other students have been sent out on the training ships *Ekvator* and *Polyus* which, during the training voyages actually handled cargo in the export-import trade. *Ekvator,* in 1959-1960, for example, carried some 6000 tons of general cargo between ports on the Black and Mediterranean seas. All operations connected with the cargo were handled by students. The schools now control three training ships, each of which has a cargo hold of 350-400 tons capacity. On the Caspian, for example, *Volodya Dubinin* with a capacity of 1,000 tons has been assigned as a training ship and is in use by the Baku Maritime School. Plans call for replacement of the old training ships with new ones, equipped with modern equipment and instruments. As yet no determination as to the method to be used to control study and teaching when ships sail on long voyages, particularly when the students are involved with complex subject matter.

S. Khayurov, Chief of the Educational Institutions Division of the Ministry for the Maritime Fleet, accuses many of the captains, mates and engineers of inattention to training matters, many of them not being sufficiently trained themselves to assist students. He expects the schools to send out qualified people and to make their own arrangements to provide the needed guidance and instruction.

The schools, in turn, are devising new approaches to the problem and certain examples can be cited. The Vladivostok Higher Marine Engineering School will require its graduating students to present projects which have close connections with actual production problems, projects which will have to contain specific suggestions on how to modernize methods presently in use and how to improve economic indices. The Odessa Maritime Fleet Engineering Institute is starting a new series of special courses dealing with training engineers in how production processes in ports and in ship repair yards can be automated. Other engineers are to be trained in economics as a separate discipline. The Gorkiy Water Transportation Engineering Institute, a river institution, gets most of its first year students from right off the job, but since most of them have a good bit of practical experience the Institute has been revising its correspondence course base and, with the 1260 correspondence course students enrolled this year, has a total of 3500 students in various of its courses.

TANKER FOR EAST GERMANY

The 16,000 ton displacement tanker of the *Kazbek*-class, built for East Germany in the Admiralty Shipyard in Leningrad, was run over the trial grounds in the Baltic in July. Named *Tsayts,* the tanker will be homeported in Rostock.

Another tanker of the same class, *Belen,* also for East Germany is ready for launching.

WHALER BASE SOVETSKAYA ROSSIYA

The I. I. Nosenko Shipyard has started dock trails on the latest of the whaler bases building in the Soviet Union. Trials of the main engines, the industrial equipment, refrigeration installation and other equipment were reported in progress in mid-July. It can be anticipated that *Sovetskaya Rossiya* will participate in the whaling season which is coming up shortly.

RIVER PASSENGER SHIP ADDITION

The three-decked passenger ship *Ivan Susanin,* built in East Germany for the Soviet Union, arrived in Moscow in time to open a run between Moscow-Kuybyishev-Moscow late in July. The motorship will make the run, something over 2000 miles, in 12 days.

PASSENGER SHIP FOR THE CASPIAN

The Vano Sturua Shipyard in Baku is reported ready to launch a passenger motorship named *Sulak,* the first such built in Azerbaydzhan. The ship is to operate between Astrakhan-Bautino-Guryev, an area of shallows. Aluminum and manganese castings have been widely used to reduce weight in order to meet draft requirements and still carry 130 passengers in air conditioned cabins. Further construction of the type is planned.

HEAVY-LIFT CRANE DELIVERY

An August report cites the arrival of a 100-ton lift capacity floating crane having arrived in Klaypeda for use in the maritime port. The crane was built to Soviet order in Hungary.

RIVER CARGO CARRIER CONSTRUCTION CONTINUES

The last isue of the "Journal" reported the construction of *Volgo-Don* 1, first of a series of river carriers of 5000 tons capacity. The number of the class afloat had, by August, increased to three, with *Volgo-Don* 3 running trials on the Gorkiy Sea. However, the latest of the series has no transverse bulkheads, and instead of four holds has but one, some 328 feet long. At this writing trials in the stormy weather usually anticipated on the Kuybyishev reservoir should be underway in an effort to determine if the design is capable of withstanding the stresses imposed by such weather.

SHIPBUILDING IN BULGARIA

The Georgiy Dimitrov Shipyard in Varna is engaged in building steel and reinforceed concrete ships, not only for own use, but for export as well. In addition the yard engages in repair work on these same types.

Production includes steel passenger motorships with speeds up to 14 knots and passenger capacities of 150, dry cargo motorships with deadweights of 200, 400, 800, 3150 and 5000 tons.

Repair work is done on a slip which can lift ships weighing up to 800 tons and a dry dock measuring 720 x 89 feet, the latter serviced by two cranes capable of handling 15 and 30 tons respectively.

Reinforced concrete ships are built on four transverse ways and the building cycle calls for about 75 days to erect the framing, 5 days (in three shifts) for the pouring of the concrete, and 30 days for drying of the hull. Launching is done on carriages. These hulls are built up into barracks ships housing 130 men, including a 31 man crew. All living and cultural facilities are housed in the hull which has the following characteristics:

Length overall, feet	226
Length between perpendiculars, feet	210
Beam, feet	44
Draft, feet	7.4
Displacement, tons	1745

Other types include non self-propelled canneries which are outfitted to process 15 tons of fish per hour on the fishing grounds. This type has a hull which is 143 feet long, 31 feet in the beam, and draws 9 feet. A main generator rated at 25 kw, and a 7.2 kw auxiliary generator, are installed equipment. This same hull, when loaded with agricultural products, draws nearly 15 feet while carrying 500 tons.

Perhaps the most interesting of all is the 3200 ton deadweight, seagoing tanker with the following dimensions:

Length overall, feet	308
Length between perpendiculars, feet	295
Beam, feet	49
Draft, feet	21

The main engine is rated at 1200 hp and the speed is said to be 16 knots. A crew of 39 men will be needed to service the ship, which has a steel superstructure set on the reinforced concrete hull. The bottom thickness runs to 4 inches, the sides slightly less. Decks are slightly more than 3 inches in thickness, while bulkheads range from 2½ to 3 inches.

The yard is said to be engaged in studying the possibilities of building reinforced concrete floating docks, cranes and other technical units.

Other construction takes place in the yards in Rus and Burgas, including the construction of 3200 ton capacity cargo ships, steam propelled passenger ships, river tankers with 4000 tons capacity and floating repair bases.

SHIPBUILDING IN HUNGARY

Building for use on the Danube is a river icebreaker 105 feet in length, 24 feet in beam, drawing almost 5 feet on a displacement of 162 tons. The ship can be used as a tug as well.

The main engine is a supercharged diesel rated at 600 hp at 310 rpm.

SHIPBUILDING IN POLAND

The 1961 plan for shipbuilding in Poland called for building 65 ships with a total of 300,000 dwt, an increase of over 45,000 dwt as compared with 1960. Employment increase for 1961 over 1960 has been listed as 3 percent.

First quarter 1961 production was 13 seagoing ships with a total 64,915 dwt. This is an extension of 1960 production which, according to Polish sources, saw Poland take first place in the world in the production of factory trawlers and base ships for the fishing fleets throughout the world.

Polish representatives, meanwhile, met with USSR officials to work out the details of the export agreement which, over a five year period, calls for delivery to the USSR of 44 ships of various types with a value of 442 million zlotys in foreign exchange. Added to previous agreements, this number runs the figure for the period 1961-1965 to 77 ships of various types, all apparently to be built in Gdansk.

Merchant Marine Additions

Name	*Where Built*	*Type*	*Grt*
Abruka, m/v	—	Cargo	—
Adimiles, m/v	Poland	Timber Carrier	4600
Aga Neymatulla	—	Crane Ship[1]	—
Aldanles, m/v	Poland	Timber Carrier	4600
Arkhangelskles, m/v	Poland	Timber Carrier	4600
Arman, s/s	Poland	Fish Factory	11540
Chernomorskaya-1, m/v	USSR	Scow	—
Egersheld	USSR	Refrigerator[2]	—
Gundulich, m/v	—	Cargo	—
Gyurgen	—	Cargo[1]	—
Leon Paeglye, m/v	Poland	Fish Factory	2670
Nagayevo, m/v	—	Cargo[3]	—
Nikel, m/v	—	Cargo	—
Pavel Chebotnyagin	USSR	Fishing Base Ship[4]	—
Ployeshti, m/v	—	Cargo	—
Poltava, m/v	USSR	Cargo[5]	—
Poseydon	—	Salvage Tug	—
Pskov	—	Dredge	—
Purga, d/e	USSR	Port Icebreaker[4]	—
Ruslan	—	Training Ship[6]	—
Split, m/v	—	Cargo	—
Sputnik, m/v	Poland	Trawler	2670
SRT-1172	USSR	Trawler	—
SRTR-9144, m/v	East Germany	Refrigerator Trawler	508
Sulak, m/v	USSR	Passenger[1]	—
Termez[3]	—	—	
Vitaliy Bonivur, d/e	USSR	Refrigerator	5217
Yalta	Austria	Tug	—
Yevgeniy Nikishin	USSR	Cannery Ship[4]	—

1. Caspian Sea use.
2. 10,000 tons displacement. Under construction in the Baltic Shipyard.
3. Far East use.
4. Under construction in the Admiralty Shipyard.
5. Under construction.
6. For the Rostov Maritime School.

LUBES BEARINGS AT 1500°F

A new high-temperature lubricating process uses chemical coatings in lieu of conventional liquids and powders. This process chemically converts bearing-part surfaces into a multi-metal alloy with lubricating properties. Depth of treatment is about 0.000001 in. Even at 1500°F the lubricated surface takes high loads.

The Iron Age, 10 August 1961

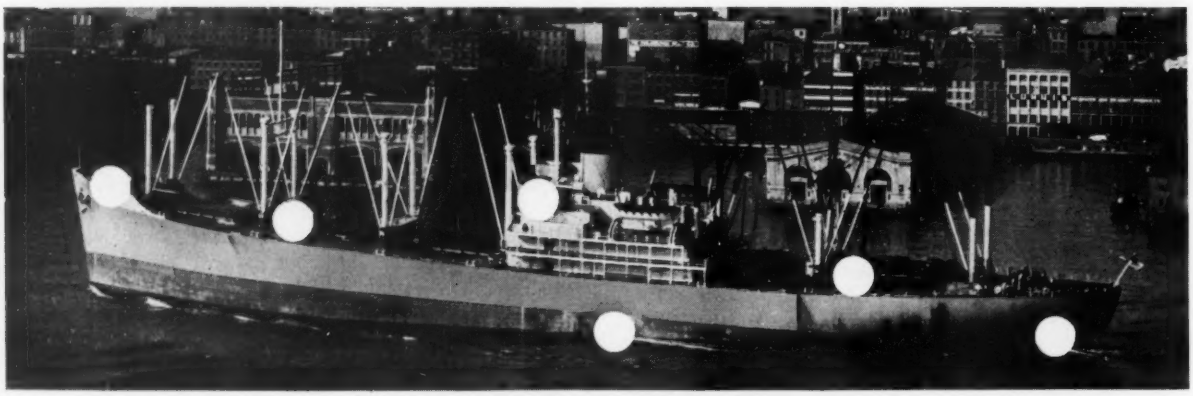
·J·J·HENRY·CO·INC·
·NAVAL ARCHITECTS · MARINE ENGINEERS · MARINE SURVEYORS ·

New York
21 West Street
New York 6, N. Y.
WHitehall 3-2870

Philadelphia
401 North Broad Street
Philadelphia, Pa.
WAlnut 5-1755

Cable: Henrycoinc

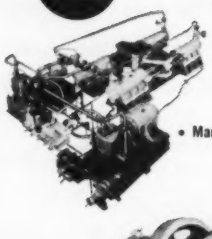
NOW ONE SOURCE FOR CONDENSERS AND EJECTORS, HEAT TRANSFER, DISTILLATION AND MARINE AUXILIARY EQUIPMENT...FOR VESSELS RANGING FROM TUGS TO SUPERCARRIERS.



C.H. WHEELER AE **GRISCOM-RUSSELL**

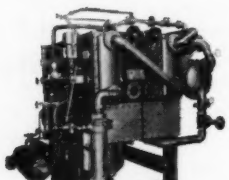
Philadelphia 32, Pa. Massillon, Ohio

• Electro-Hydraulic Cargo Cranes

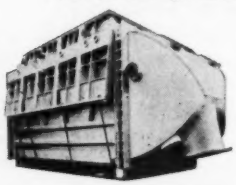


• Marine Steering Gears

• Windlasses, Capstans and Winches



• Flash and Submerged Tube Distilling Plants



• Surface Condensers

• G-Fin Section fuel oil tank heaters

"THE MARINE ENGINEER AND NAVAL ARCHITECT"

A 7500 SHP GAS TURBINE FOR NAVAL BOOST PROPULSION

ACKNOWLEDGMENT

This article was written by F. R. Harris, Chief Engineer of the Gas Turbine Department, Turbine-Generator Division of Associated Electrical Industries (Manchester) Ltd. It appeared in the May, 1961 "The Marine Engineer and Naval Architect" from which it is reprinted.

THE APPLICATION of gas turbine boost to naval ships, which was first demonstrated in a gunboat of the Royal Navy in 1947, has now spread to ships of much larger size, and the purpose of the present paper is to deal with the G.6 gas turbine, which forms part of the power plant of two classes of ships of the Royal Navy.

Design studies carried out by Yarrow-Admiralty Research Department, in close collaboration with the Admiralty and the author's company, into the best arrangement of propulsion machinery for two projected classes of ship (general purpose frigates and guided weapon destroyers) led to the conclusion that steam turbines (of reasonably advanced steam conditions) should be used for normal propulsion and maneuvering, and that the upper portion of the power range, only rarely used in these classes of ship, should be provided by gas turbines. Various ratings were considered for the gas turbine plant, and that eventually specified was 7,500 hp, measured at the propeller shaft.

The frigate and destroyer installations each used the same gas turbine, the G.6, with only minor installational differences; the frigate machinery (single-shaft) included one gas turbine and a steam turbine, driving into a common reduction gear; while the destroyer machinery consisted of two shafts, each powered by a steam turbine and two gas turbines, driving into a common reduction gear.

The G.6 gas turbine was the fifth member of the family of naval gas turbines designed and built by the author's company, which commenced with the 1947 Gatric plant.

The designations G.3 and G.5, which do not appear in the table, refer to projects which were not built; G.3 was to be a 12,000 shp machine which used the Sapphire aero-engine for the gas generator portion, and G.5 was to be a 15,000 shp machine which was investigated in connection with the requirement (for the guided weapon destroyer) for 15,000 gas turbine horsepower on each propeller shaft. After studying operational requirements and

TABLE I

Leading particulars of naval boost gas turbines

Designation	G.1	G.2	G.2/11	G.4	G.6
Year of order	1943	1948	1951	1951	1955
Year of test	1946	1951	1955	1956	1958
Specified blading life at full power, hours	300	300	300	1000	1000
Specified output at propeller shaft, H.P.	2500	4800	4800	5000	7500
Engine dry weight, lb.	4030	6950	6950	8160	41,440
Weight, pounds per S.H.P.	1.61	1.51	1.51	1.63	5.52
Reduction gear weight, lb.	2600	2770	2750	4500	—
Total weight, gas turbine plus gear,* lb.	6630	9720	9700	12,660	—
Weight, gas turbine plus gear,* pounds per S.H.P.	2.65	2.02	2.02	2.53	—
Air mass flow, lb./sec.	47.5	65.6	65.6	64	106
Compressor pressure ratio	3.5	4.0	4.0	6.3	6.3
Compressor speed, rpm	7400	7830	7830	11,000	6850
Turbine inlet temperature, °F.	1380	1470	1470	1500	1460
Power turbine speed, rpm	3600	5200	5200	6200	4900
Full load specific fuel consumption, lb./S.H.P.-hr.	1.06	.82	.82	.68	.77

* Excluding lubricating oil system and tank.

All performance figures refer to ambient air conditions of 59°F., 14.7 psia.

Ducting pressure losses are only nominal for all machines except G.6, for which the losses are 0.30 psi at exhaust, and 0.35 psi plus silencer loss at inlet.

convenience of machinery space layouts, it was decided that two 7,500 shp gas turbines were preferable; this also enabled one similar gas turbine to be used in the Frigate power plant.

DESIGN REQUIREMENTS

The G.6 gas turbine, rated at 7,500 shp at 59°F ambient air temperature had a specified life of blading at full load of 1,000 hours; the output had to be developed under conditions of duct pressure losses of 0.65 psi, plus an inlet silencer. Severe shock acceleration had to be withstood, and an additional requirement was that the gas turbine had to be airtight, so that the air passing through the machine did not leak into the engine room. The machine had to be capable of operation *partially submerged in water;* and starting and control of output were to be effected remotely.

The cycle chosen required a compressor pressure ratio of 6.3 and a turbine inlet temperature of 1460°F (1470°F at 90°F ambient air temperature, when 6,750 shp was specified). The predicted specific fuel consumption at full load was just over 0.72 lb/shp-hr.

In order to obtain full benefit from the quick-starting capabilities of the gas turbine machinery, provision was made in the reduction gear for driving the propeller shaft in either direction, so that maneuvering of the ship on gas turbines only was possible. The reduction gear already contained automatic over-running clutches of the S.S.S. type so that the L.P. turbine of each gas turbine was disconnected except when it was providing power; by this means the problem of power loss due to windage was avoided.

The mechanical construction of the G.6 gas turbine was a good deal heavier than in previous boost gas turbines. This was for two reasons: shock acceleration requirements required a certain amount of increased rigidity, but, more important, was a determination on the part of the designers and the Admiralty, that the G.6 machine should, so far as was humanly possible, be free from all the troubles which had been experienced on previous boost machines.

By the time of the initial conception of the G.6 machine, Admiralty experience with several lightweight propulsion gas turbines, based on aero-engine concepts, had shown that, for one reason or another, ball and roller bearings did not seem to be suited to naval propulsion machinery, and both G.4 and G.6 gas turbines used sleeve journal bearings and Kingsbury thrust bearings for that reason. This experience indicated that no existing aero-engine should be used, without conversion to white-metal bearings, as part of a naval propulsion gas turbine for vessels of the size and importance then contemplated.

Current aero-engines have the highest reputation for performance and reliability, but the development cost of a new model is such that it needs to be sustained by sales of thousands of units; and the cost of modification of a "standard" model to incorporate, for instance, white-metal bearings, would also be high. Naval gas turbines of the ratings concerned would be required in dozens or, at the most, a hundred or so, and the cost of development cannot be spread over large numbers of units. Such considerations, together with several other important modifications which would be required for naval purposes, justified the design of the G.6 as a completely new machine, especially tailored to its specification.

Because of the desire to keep the development cost within limits, it was considered prudent to

adopt design criteria somewhat more conservative than those applicable to aircraft practice; the naval gas turbine has to be right, or at least nearly right, first time, and a too-ambitious project may lead to a disappointingly large amount of development in order to succeed.

DESIGN HAS TO BE RIGHT FIRST TIME

At the time of the G.6 design, the difficulties due to rotating stall in variable-speed compressors were being encountered in aero-engines, but there did not appear to be any easy way out of this trouble, except to reduce the blade loading below the point where the vibrational stresses induced could cause failure. The G.6 compressor blading, as a result, is of markedly more robust design than that used in previous naval machines. Consideration of a somewhat similar nature led to the use of more robust turbine blades.

One effect of the use of wider-chord blades is, naturally, to increase the size and weight of rotors, cylinders, and many other components; and Table I shows how the weight per horse-power of the G.6 has increased compared with earlier machines; only a small part of this increase is due to "square-cube law" effects, although some increase is undoubtedly due to the provision for loading by shock acceleration.

TEST INSTALLATION

The extent of the Admiralty's commitments in respect of the G.6 machine was reflected in their determination that no part of the plant involving any untried principle should go to sea until shore testing had, so far as was possible, demonstrated its ability to meet its duty. To ensure the implementation of these requirements a special test plant was laid down at the builders' works, simulating one propeller shaft set of Destroyer machinery, except for the steam turbines. This consisted of two gas turbines, a reduction gear and its associated clutches, a hydraulic dynamometer of 10,000 hp for power measurement, and duplicates of the remotely-operated shipboard controls. The two "shore trials" gas turbines were completed and run well ahead of those turbines destined for ship installation, and a great deal of development, involving minor changes both to the gas turbines and to the reduction gear, was carried out; if the development had had to be done in a ship at sea the difficulties would have been enormous, the time taken completely unacceptable, and the cost (including that associated with the ship and its crew) astronomical. The whole "shore trials" installation remains a tribute to the foresight of the Admiralty in this respect.

DETAILS OF CONSTRUCTION

The annular combustion chamber, used in all previous designs, was abandoned and six flame-tubes were used. This offered the facility of a machine completely split at the horizontal joint for access; no other condition could be tolerated in the type of installation now contemplated. It also allowed the rig testing of combustion chambers at full load, not possible with the annular chamber. The compressor inlet casing now faced vertically upwards, not axially as in previous machines. The compressor blading was completely in aluminum bronze, which had the highest fatigue strength, in a marine atmosphere, of any alloy available at the time of design. The compressor fixed blading was unshrouded at the outlet end, but at the inlet end five stages were built into diaphragms, as in conventional steam turbines. This was necessary to ensure freedom from blade vibration.

Both turbines were two-stage, overhung back to back, and each turbine casing was fitted with liners to reduce distortion due to temperature gradients. Light alloy castings, used extensively on previous machines, could not now be used for structural parts because of the severe shock requirements, and steel fabrications took their place. A large lubricating oil pump was driven from the compressor, and formed part of the main lubricating system of the propulsion machinery. Starting was by compressed air, after exhaustive analyses of many other methods. Six motors (developed versions of an Admiralty torpedo motor) were used, driving through sun-and-planet gears on to the compressor shaft. An over-running clutch of the S.S.S. type was provided for disengagement. The motors operate on air stored at 3000-4000 psi and supplied to the motors at 600 psi. At this pressure, each motor is capable of 43 hp peak output, at 4000 rpm. During the starting cycle the motors disengage at 3200 rpm, at which condition the output of each is 41 hp. Each start requires about 1100 cu. ft. of free air. The motor capacity is large enough to ensure starting at air supply pressures down to about 450 psi. Ignition was by magneto, driven from the starter gear train. This system, together with the ability of starting from air stored in bottles, and of providing sufficient lubricating oil for starting by means of a hand-operated pump, offered the facility of starting the gas turbine in emergency in a completely "cold" ship, i.e., without electricity supplies of any sort. Provision for increased ease of maintenance was made; all top half casings, and rotors, can be lifted on screwed columns for inspection. Large components, such as the compressor inlet casing and the turbine exhaust, were subdivided into small pieces for ease of handling.

The gas turbine is mounted completely on a sub-frame, which is designed to be strong enough to transmit to the ship's seating the forces arising out of shock loads due to underwater explosions. It so happens that the deck openings required by the gas turbine ducting are large enough to admit each major component of the machine, with the exception of the sub-frame. This means that the whole gas turbine may be removed and replaced, piece by

piece, if required, without having to cut special apertures in the deck; a facility which is rare in respect of propulsion machinery for naval vessels of this size.

The normal fuel is gas oil (a distillate) but provision is made (as specified) for burning untreated furnace fuel oil in emergency, although it is accepted that the turbine may be damaged as a result.

TESTING

The first gas turbine was programmed for completion some time ahead of its reduction gear, so testing with power absorption by the conventional method was not immediately possible. By running with a variable-area nozzle in place of the L.P. turbine, it was not difficult to run the compressor and H.P. turbine over a wide range of operating conditions, including full load, without the use of reduction gear or dynamometer. This facility has been of the utmost value; the G.6 turbine is being manufactured in Britain by several shipbuilders as well as by the author's company, and the expense of several sets of power-measuring equipment could not be considered. But, by running with a nozzle in place of the L.P. turbine, the gas generator portion of each machine can be given a mechanical run to full load, and sufficient test readings can be obtained to enable reasonable predictions of its performance to be made, by direct comparison with the prototype machine, tested both with a nozzle and with a dynamometer. No major design modification has been found to be necessary as a result of the experimental testing, although a great many minor improvements have resulted from the running.

The compressor was rig-tested in three slightly different builds, before running the gas turbine. The characteristics of the three builds were closely similar. The surge pressure ratio of the compressor actually used, at medium and high speeds, was surprisingly high. One machine was built with an 11-stage compressor instead of the standard 13-stage. The overall performance was not much different, but the 11-stage engine proved difficult to start particularly when hot, without the use of compressor bleed, which was not required in the 13-stage build. No major vibrational stresses were recorded apart from those associated with rotating stall; these occurred at compressor speeds below 5000 rpm, and the robust proportions adopted for the blading (largely on this account) were sufficient to limit the stresses to very moderate values.

The mechanical construction of the compressor rotor, with discs separated at the periphery by interstage rings, was such that a fixed blade tip rub automatically made itself worse by reason of local expansion of the rubbed (and heated) portion of the ring; and one such rub was experienced in early testing. The short-term solution was adopted, of increasing the compressor blading tip clearances; some price is undoubtedly paid in compressor efficiency, but reliability was put before fuel economy.

The initial design of combustion chamber, while allowing satisfactory operation up to full load, was unsatisfactory in that the exhaust was smoky, a most undesirable situation in a naval ship. A good deal of experimental development was carried out, in collaboration with the National Gas Turbine Establishment, involving the rig operation of an experimental chamber at full load, and, by changes to the airflow conditions in the chamber, the smoky exhaust was eliminated.

Lubrication of the starting motors is by means of oil carried in with the air supply, and shortage of oil leads to excessive piston wear. In the final system, "pre-wetting" of the motors is employed for an instant before the application of full air pressure, so that the motors always start in the "wetted" condition.

The requirement for an airtight gas turbine gave considerable trouble; no glands leaking to atmosphere were used, and bearing space vents were piped outside the gas turbine. At first a good deal of oil escaped with vented air, and considerable development running was necessary before a system was evolved which did not consume an unacceptable quantity of oil, and which did not cause trouble in other ways. In this scheme, most of the clean air vents (from compressor gland leaks, etc.) are piped direct to the turbine exhaust, while air containing oil vapor is led to a separate vent tank, which is piped to atmosphere outside the engine room.

One of the desirable features of a boost naval gas turbine is its facility for rapid starting and loading. The starter motors of the G.6 are in engagement for only about 20 seconds during a normal start, and full power has been achieved from a cold machine in 3½ minutes. Some temperature variations associated with rapid starting are shown in figure 1 which depicts temperatures of cylinder casing and liners of the H.P. turbine during a start. The interesting feature is the relatively slow heating rate of the casing itself, even though the liners, which are subjected to the full gas temperature, heat very quickly.

Provision is made for removing salt deposits in the compressor by washing with distilled water, sprayed into the intake at about 2/3 full speed; this method has been used on previous naval machines. This method of restoring full power is completely successful only when the deposit on the compressor blades is water-soluble, such as the salt deposited after operation in clean sea air. Test running in a heavily industrialized locality where, in spite of air filters, a black oily deposit adheres to the compressor blading has shown that spray washing with various mixtures of water and detergents will not maintain full power unless carried out daily.

The test results of the G.6 turbine are shown in figures 2 and 3. These figures are corrected to

59°F., 14.7 psia, and are also corrected to the specified full power ducting losses (0.35 psi, plus a measured silencer loss of 0.4 psi at inlet, and 0.30 psi at exhaust). It will be seen that the originally quoted figure for specific fuel consumption at full power (0.71 lb/shp-hr) has not quite been met (test figure is 0.77 lb/shp-hr). Work is in hand towards effecting a recovery of this short-fall, but is at present second in priority; the major development effort is, quite correctly, to ensure the reliability and readiness for use of the gas turbine, rather than to obtain the last ounce of efficiency from it.

FUTURE DEVELOPMENT

There are better creep-resisting blade alloys in existence today than in the days when the G.6 machine was first designed. This obviously allows for some benefit to be obtained by a change in alloy; but it is not considered prudent at this stage to increase the turbine inlet temperature above about 1520°F.

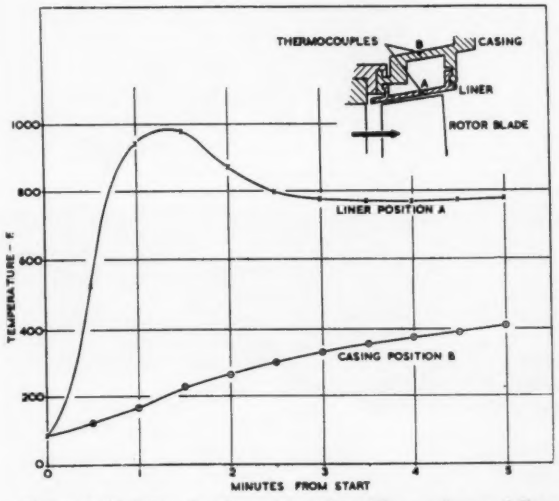


Figure 1. Relative heating rates of turbine casing and liner during normal start.

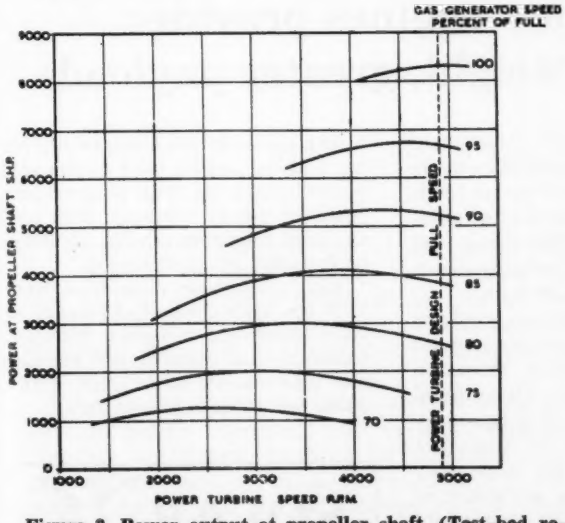


Figure 2. Power output at propeller shaft. (Test-bed results, corrected to allow for the specified shipboard ducting losses.)

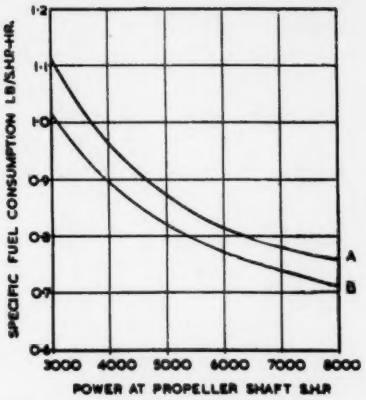


Figure 3. (A) Specific fuel consumption (Test-bed results corrected to allow for the specified shipboard ducting losses). (B) Specific fuel consumption with ducting losses of 4 in. water at inlet and 6 in. water at exhaust.

Experience in an earlier naval machine (G.2) had shown that damage was caused to the turbine blading after operation in very rough weather (intended to demonstrate the sea-keeping qualities of the vessel), due to chemical attack by a mixture of sodium chloride and sodium sulphate (formed in the combustion chamber from the ingested salt and the sulphur in the fuel). Laboratory investigations showed that this attack occurred catastrophically at temperatures above about 1560°F.

Bearing this prudent figure of 1520°F. in mind, the main improvement made possible by the use of the newer alloys is in blading life. The original specification was for 1000 hours life at full load; the materials chosen were such that this could be achieved comfortably so that if deterioration of performance occurred in service because of compressor fouling or any other reason, the specified output could still be achieved. The newer materials make possible a blading life of at least 10,000 hours at full load, with the same facility for maintaining output in service. For an ambient air temperature of 59°F., and a turbine inlet temperature of 1520°F., the output at the propeller shaft would be 8500 H.P. (or, at turbine coupling, 9100 H.P.).

Operation of the G.6 gas turbine on land now totals over 1400 hours, of which about one-third have been at or near full load. The first frigate goes to sea early in 1961, and the first destroyer later that year. Seagoing experience will undoubtedly reveal the possibilities of further improvements to the gas turbine design, and the operation of the plant at sea is awaited with great interest.

Solar marine gas turbine engines provide compact horsepower, light weight, greater payloads

Solar's *Saturn* 1100 hp gas turbine is a true marine engine that provides a high level of performance with less weight and smaller space requirements than conventional reciprocating diesel or gasoline engines.

The *Saturn* engine is an ideal powerplant for any kind of craft over 50 ft long, including fishing, commercial, pleasure and work boats. It is currently scheduled for a variety of Navy and Coast Guard craft, including the 82 ft patrol boat shown above.

Compared with conventional marine diesel engines of similar horsepower, the Solar *Saturn* turbine weighs one-tenth as much and occupies one-seventh as much space.

Solar gas turbines start instantly and accept full load without warmup in temperatures from below zero to 130 F. Starting systems can be electric, pneumatic or hydraulic. The engine will burn a variety of fuels, including diesel, gasoline, kerosene and jet fuels.

Simplicity of design means that Solar marine gas turbine engines are easy and inexpensive to maintain. Vibration problems are eliminated. Heavy foundations or mountings are unnecessary.

Solar marine gas turbines are designed for the long life, heavy duty requirements of marine and industrial applications. Every part is carefully engineeered to give economical service under the most rugged conditions.

The versatile Solar *Saturn* marine gas turbine can be used as the sole power source for high performance boats, or can be combined with conventional engines to provide ultra-high performance for short periods.

Solar gas turbines range from 50 to 1100 hp. They are backed by over 15 years experience in turbine research, technology and manufacture. For further information, write Dept. J-163, Solar, San Diego 12, California.

SOLAR

A subsidiary of International Harvester Company

S. G. BRALEWSKI

UNDERSTANDING AUTOMATIC COMBUSTION CONTROL

THE AUTHOR

After some nineteen years of naval service, fourteen as a Chief Boilermaker and Chief Boilerman aboard tenders, destroyers, aircraft carriers, and three years in engineering experimental work, I find myself retired from the Navy, engaged as a service engineer with an automatic control company. My introduction to automatic combustion controls, ten years ago, was much the same as it is today for the average boiler operator. Only by refusal to accept a mechanical, pneumatic, electric or hydraulic "monster" that was doing my job as beyond my understanding, could I, or can anyone else, master automatic control systems. As a teacher, primarily, I have taken some liberties to maintain the desired simplicity in comparison in the article. The purpose is to get the operator to feel that controls can be understood and that existing instructions, schematics and blueprints can enlighten him further in mastery of automatic combustion control. With a basis in the relationship between automatic control and manual control the average man with initiative and desire "to know" can "know" by applying himself to the task.

AUTOMATIC COMBUSTION control with boilers has been with us for many years in the merchant marine and in stationary power plants. In the last decade the navy has seen fit to adopt controls to aid operating personnel in doing their jobs more efficiently.

Prior to the general acceptance of controls, man steamed boilers manually with understanding and complete confidence, knowing the functions necessary to maintain optimum boiler efficiency. Each man knew his job and its relation to the overall boiler operation. Suddenly these men are faced with automatic control. The majority lose their understanding and confidence, because on the whole they are told automatic control is very complicated and besides, "it's all automatic, so you don't have to worry."

It is my contention that this routine approach has retarded the understanding of automatic controls and constitutes a dangerous situation for the men and the equipment concerned.

There has to be, and there is, a definite relationship between manual operation and automatic operation of a boiler.

First we take the existing factors involved, which heretofore boilermen were aware of. A steam pres-

sure gage is the primary element of the boiler's operation. In order to maintain a desired pressure, a close watch is kept on the gage. Any deviation from the set pressure puts the operators into action. To maintain this set pressure, air fuel and water must be introduced to the boiler in a definite order and ratio. The man on the boiler feedwater valve maintains water flow, the man on the burners maintains fuel flow, and the man on the forced draft blowers maintains air flow, with overall coordination maintained by the man in charge of the watch.

The components of an automatic control system can readily be compared to the same situation. A steam pressure transmitter is the steam pressure gage. The steam pressure controller is the man in charge of the watch and coordinates the fuel, air and water flow to the boiler to maintain the desired set steam pressure. The automatic fuel control valve is the burner man. The forced draft blower speed and damper control is the blower man. The automatic feed control valve is the feed check man.

On direct manual, an increase in boiler load is indicated by a drop in steam pressure on the steam pressure gage. The top watch notes this change and puts the blower man into action to increase air flow, and in turn the burner man follows up with an increase in oil flow to bring the steam pressure back to normal. The feed check man is informed of the load change by the sound of firing rate increase and verbally, the degree of change. With this information he knows he will have an initial rise in water level due to "swell," but he also knows that an increase in water flow is pending. Taking "swell" into account, he adjusts the feed valve as required to maintain proper water level.

On automatic, the same chain of events takes place. An increase in load is sensed by the steam pressure transmitter and a signal is sent to the steam pressure controller. The controller becomes aware of the need for a firing rate increase, sending a signal to the air flow controls to increase blower speed and open dampers. The increase in air flow is the signal for the oil control valve to increase oil flow. As steam pressure returns to normal the steam pressure transmitter signals the controller and the controller settles out the air flow and oil flow controls at the new firing rate.

The automatic feed control is aware of the increase in load by an increase in steam flow and is aware of the "swell" through its level sensing element. It takes "swell" into account but knows an increase in feed flow is in order and opens the feed valve as required to maintain proper water level.

At this point, if the direct manual boiler operator can be aware of the fallacy of his introduction to automatic control, he can visualize the fact that the control system is doing his job, along with the jobs of his fellow watch standers, to maintain steam pressure with optimum efficiency. Accepting this fact reduces much of the "complexity" of automatic control.

The next "barrier" to understanding thrown in his path is terminology and nomenclature used in association with control, relative to its direct manual counterpart. Terminology is well on its way to standardization. Nomenclature, however, will tend to vary due to the desire for individuality of the various control companies.

Standard terms such as set point, proportional band, reset action, rate action, feed back and dead band, with some reservations, can readily be compared to direct manual operation functions.

In direct manual operation the experienced man maintains the desired steam pressure and knows, by the amount of steam pressure deviation, how much air, oil and water correction is needed to restore the steam pressure to normal. He also knows the desirable length of time he has to make the changes, whether they are sufficient in magnitude, whether overfiring or underfiring his final settling point for a short period is desirable for best results, and whether his actions are effective.

An experienced crew may take a steam pressure deviation of plus or minus 60 psi on a 1200 psi plant for major load changes. The steam pressure would go to 1260 psi before they would go to a minimum firing rate, and 1140 psi before they would go to a maximum firing rate. The desired steam pressure is the "set point." The amount of deviation, plus or minus from set point required to drive the controls from minimum to maximum firing rate, is the "proportional band" and is expressed percentagewise. As in the case of the experienced crew, a span of 120 psi relative to 1200 psi would be a proportional band of 10 per cent.

For a definite amount of steam pressure change the direct manual operator and the automatic control will make an immediate proportional change in firing rate, in a specific amount of time. However, if this initial change in either mode of operation, direct manual or automatic, does not restore steam pressure to set point, both modes will repeat the firing rate change until the steam pressure does return to set point. This is "reset action" and is normally expressed in repeats per minute.

Accelerating or decelerating firing rate response is done direct manually by overfiring or underfiring the final settling point, primarily for a period of time, and cancelling the tendency out as you approach set point. This action is introduced into the automatic system by a "rate action" device which overfires or underfires as is dictated, for a period of time, and cancels out as it approaches set point.

The direct manual operator, by observation of blower speed, manometer indicator and oil pressure, can tell if his actions are effecting the desired results. The automatic control derives this same information by a "feed back" signal from controlling components.

Dependent on the effectiveness of a direct manual crew and/or the automatic control system, the amount of ineffective action or lack of action, when action is in order, is "dead band" and is expressed timewise. It is the time lapse involved in any change, before effective corrective measures are taken. In either direct manual or automatic operation "dead band" is undesirable and is minimized.

The nomenclature used in automatic control components includes transmitter, controller, relay, selector station, positioner, and control drives or actuators.

Transmitters, as the name implies, send information relative to the existing state of steam pressure, steam temperature, steam flow, water level and flow, oil flow, oil pressure, and air flow. As the direct manual operator can watch and interpret the information from pressure gages, thermometers, gage glasses, manometers and the size and number of burners in use, the transmitters in an automatic system measure and interpret into relative signals the same information. Static pressure transmitters are similar to pressure gages. Flow measuring transmitters measure differential pressures and send proportional signals as to existing flow much as the burner man on direct manual can transpose the information of number and size of burners in use against the oil pressure before and after his micrometer, or oil control valve into gallons per hour, or as the experienced watchstander can tell by the pressure drop from steam drum to superheater outlet, the relative steam flow in pounds per hour.

Controllers take the signals from transmitters, as the man takes the information from gages, and transposes it into the required form of action. If steam pressure goes down, the man and controller act to increase firing rate. If water level goes down, the man and controller act to increase feed water flow.

The voice, eyes and ears of the direct manual operator are important in relaying information as to action needed coincident to the situation at hand. The varied types of relays of an automatic system are designed to perform these functions. As a vocal replacement, the relay may just repeat or introduce a volume boost to the signal. As a replacement for eyes the relay, as the man, can evaluate compounded information and send the appropriate signal for action.

Selector stations are introduced to enable the operator to have control to a varied degree of automatic, remote manual or direct manual operation. The selector station allows the signal from the preceding component to pass through to the next component on "auto" or dead ends it on "hand," allowing the operator to set up the signal, remote manually to the next component. It also enables him on "hand" to unload all of the signal and take direct manual control of the final controlled elements.

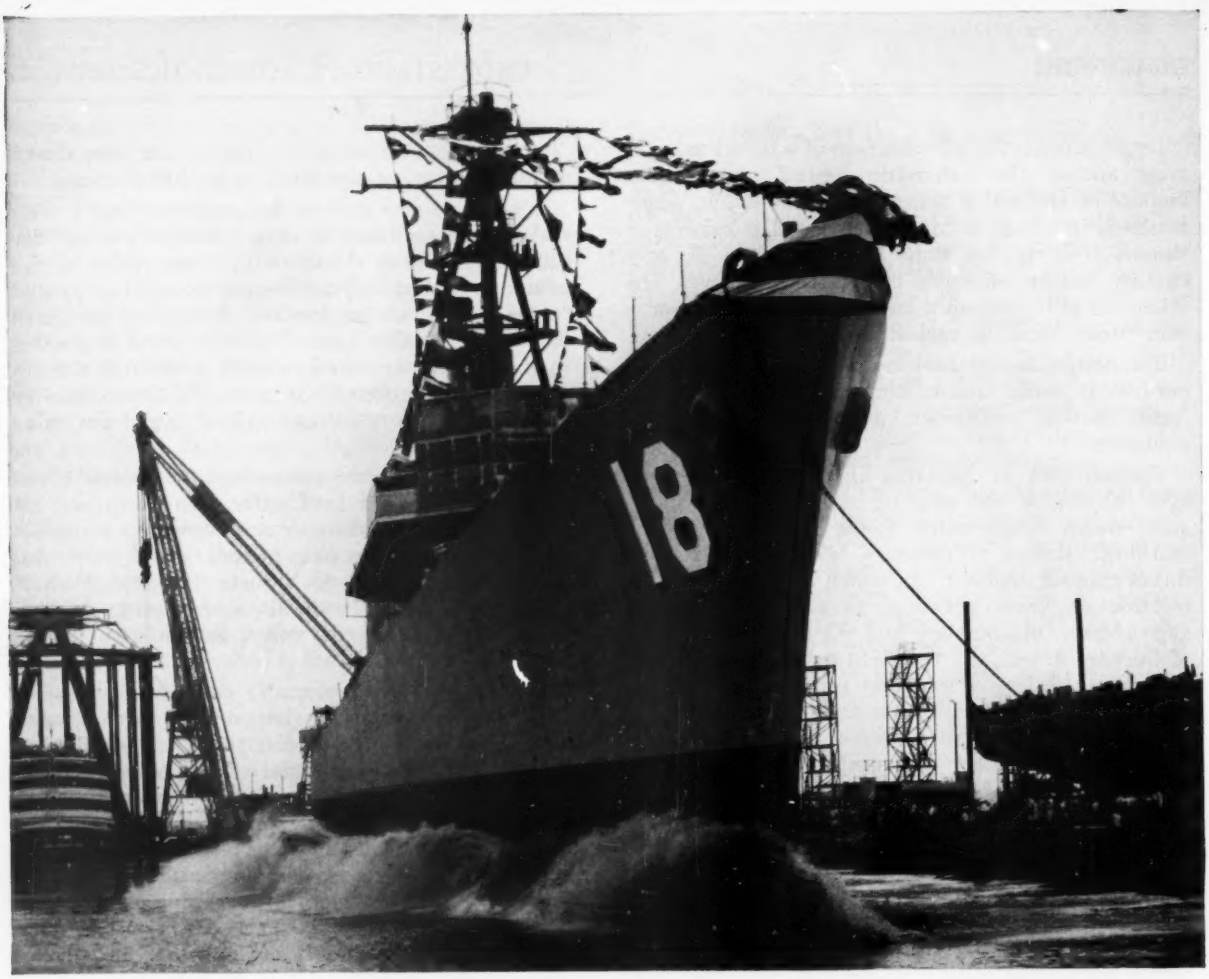
Positioners are devices designed to cause a control drive or actuator to take a definite position for each input signal change within the range of the power available, without regard to varying outside forces of friction or binding. Much as the force needed to initially open a valve by hand is greater than the force required to open it through the remainder of its travel, the man and the positioner avail as much force as is required to put the valve in the position dictated .

The final controlled elements, forced draft blowers, oil valves and feed valve. are positioned by signals to control drives or actuators. The construction of control drives or actuators is such as to provide enough power to actuate the forced draft blower throttle, move the dampers, position the oil valve and feed control valve, as the input signal dictates.

Trouble shooting automatic control is a case of reasoning out "what is happening" as to "what should be happening." Noting the what is and what should be points to the factors involved, and by isolation procedures the cause can be pinpointed. As in direct manual on a steady boiler load condition, it does happen that the feed check man and burner man lose coordination and, though the load is steady, steam pressure will vary due to the check man's manipulation of the feed check; in turn the burner man's actions will introduce a cycling effect when steam pressure should be steady. A similar cycle can be introduced in automatic for the same reason.

The man remains important to boiler operation even in automatic. The control does not daydream and remains consistent from watch to watch. However, the man's ability to think and reason still overshadows the control. Though he may not be as fast as the control, he must understand it to the extent of knowing when something is wrong and what to do about it. In direct manual or in automatic, when men or the control devices are doing their job properly, "Mickey Mouse" could be in charge of the watch. But when malfunction is introduced by man or controlling devices, the intelligence of the key watch standers determines whether confusion will reign or proper procedure will be taken, through knowledge and experience, to eliminate or minimize possible casualties to equipment or personnel.

Men in supervisory capacities should encourage and feed information to subordinates relative to automatic control. With developed initiative and assistance from those who know, the average man can become competent in understanding and handling automatic control systems. With knowledge and understanding the statement "Controls are no good" will fade into oblivion.



Launching USS SEMMES at
Avondale Shipyards, Inc., Avondale, La.

USS SEMMES

one of five new Guided Missile Destroyers to be powered by

C-E V2M VERTICAL SUPERHEATER BOILERS

Almost a third larger than destroyers of World War II, these new DDG's will have better seakeeping qualities and a longer cruising range. They will act as screen units for task forces and convoys, work with hunter-killer groups, and support amphibious operations. Each will be equipped with 4 C-E Vertical Superheater Boilers.

The C-E V2M Vertical Superheater Boiler offers maximum protection against slagging by eliminating slag-collecting, horizontal tubes. Parallel superheater tubes and generating tubes provide more effective soot-blowing. Fewer manual cleanings reduce maintenance costs. Since vertical superheater tubes permit supports to be outside of the gas pass, the expensive maintenance associated with any type of fire-side support is eliminated. For inspections and routine maintenance, excellent accessibility is provided throughout the boiler.

COMBUSTION ENGINEERING

C-335

General Offices: Windsor, Conn.
New York Offices: 200 Madison Ave., New York 16, N. Y.
Canada: Combustion Engineering-Superheater Ltd.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

"THE SHIPBUILDER AND MARINE ENGINE BUILDER"

THE AUTOMATIC CONTROL OF NAVAL BOILERS

ACKNOWLEDGMENT

This article is a reprint of a condensation by the staff of "The Shipbuilder and Marine Engine Builder" which appeared in the Annual International Number (April 1961) of that publication. The full text appears in Transactions of the Institute of Marine Engineers, Volume 73, Number 4 of April 1961.

INTRODUCTION

The Reasons for Fitting Spill Burning Systems

THE OBJECTIVES in the case of H.M.S. *Tiger* were that the boilers should be capable of remote operation over the whole range from main steaming stand-by condition to full power. It was thought that a spill burning system, combined with the Admiralty Suspended Flame Wide Range Register, could enable the necessary turn-down to be achieved and that, with little additional complication, fully automatic control could be provided. It is important to note here that the proportion of time spent maneuvering in a naval vessel is considerably higher than in the average merchant vessel and that the rates of maneuvering are frequently higher.

The Basic Spill System

Figure 1 shows the type of spill atomizer fitted in H.M.S. *Tiger*. Oil enters through the outer tube in the burner body *A* and passes through the feed-plate holes *B*. It then enters the swirl chamber *C* *via* the tangential slots *D* in the swirl plate. Some of the oil is then sprayed into the furnace *via* the final orifice *E*, the remainder passing through the helical slots *F* in the pintel and away through the central hole *G* in the burner body. The quantity of oil spilled through *G* depends upon the opening of the spill control valve, which is fitted downstream of *G*.

The Fuel System in H.M.S. "Tiger"

The complete fuel system of H.M.S. *Tiger* is shown diagrammatically in Figure 2 and consists of

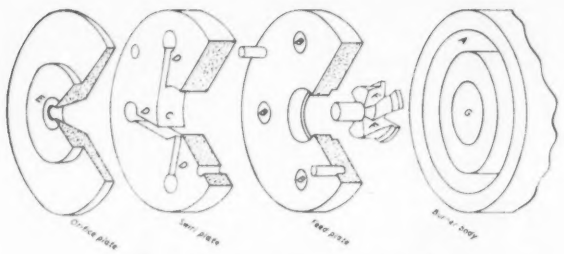


Figure 1. H.M.S. Tiger—Spill Atomizer.

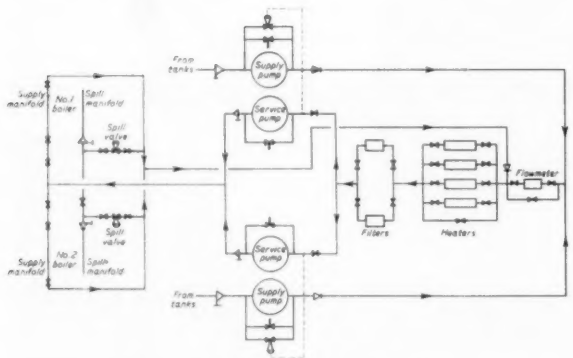


Figure 2. H.M.S. Tiger Fuel System.

two, two-stage pumps, each of which is capable of supplying either or both boilers at full power through common heaters and filters. One pump is run at a time, the other normally being left in a stand-by state. Arrangements are fitted for the remote operation of the pump turbine stop valves, so that the stand-by pump may be started in the event of a defect in the other. The two boilers are normally operated as one, as are the two spill valves, which can be ganged together.

The Original Control System in H.M.S. "Tiger"

The pneumatically-operated combustion-control system originally fitted in H.M.S. *Tiger* was very simple and consisted basically of programmed blower control and spill-valve openings giving the required air/fuel ratio at any boiler output. The operating signal to the blower control and spill valves was taken either from the steam-pressure controller or from a servo/manual control. The two blowers were operated by separate sequential nozzle control valves, positioned simultaneously by a common air motor. The programming of blower control and spill-valve openings was intended to be achieved by profiling cams in the positioners of the two valve operators concerned. Automatic control of fuel temperature was also fitted. Boiler-feed regulation was by a conventional single-element level control actuated by feed pressure.

SEA TRIALS IN H.M.S. *Tiger*

Trials under Steady Steaming Conditions

The boilers were steamed at selected different powers and sets of readings taken of the data relating to fuel and air requirements. This was done partly to prove the combustion satisfactory over the whole range and partly to obtain the information necessary to repeat these readings automatically. The fuel-temperature control was satisfactory from the first and was left in "automatic." The dotted lines in Figure 3 show the results obtained in terms of register draft loss, and it will be seen that the clear funnel range at low boiler outputs was extremely narrow. This was due to the use of fixed area registers, resulting in very low air velocities at low fixed rates with attendant loss of flame stability.

The air/fuel ratio relay was now adjusted to give the required register draft losses at minimum and maximum spill-valve positions. Due to the unsatisfactory characteristics of the blower nozzle control valves, it was found that the slight mechanical backlash existing in the valves was sufficient to cause a large hysteresis effect in blower r.p.m. and hence air flow. The effect of this upon register draft loss, which is a function of airflow per register, is shown in full line in Figure 3. It was obvious, therefore, that it would prove impossible to keep the funnel clear when operating at low boiler powers in automatic control. This is, of course, no reflection upon the valves, but merely illustrates the danger of the use of valves not specifically designed for automatic control.

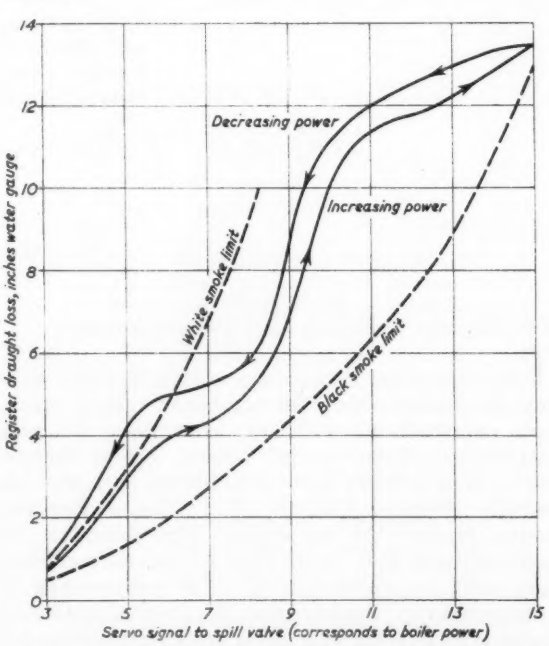


Figure 3. H.M.S. Tiger Register Draft Loss in Automatic Control.

Another equally disturbing effect of the backlash was mis-matching of the speeds of the two blowers for a given valve operator position. This, from time to time, caused one or other of the blowers to reduce speed to the extent that a dangerously low lubricating-oil pressure occurred. Adjustment of the low speed stop on the valve positioner to cure this either resulted in a too-high or too-low minimum speed.

Divergence from the Designed Supply/Spill Pressure Relationship

Early in the sea trials, several limitations of the system were found. The worst of these was that large departures from the designed burned flow characteristic were taking place in the following circumstances:

(*a*) A change in the number of burners in use without attendant change in pump speed.

(*b*) A change in pump speed without an appropriate change in the number of pumps or burners in use.

(*c*) A change in the number of pumps in use per boiler, *e.g.*, when changing over pumps or boilers.

(*d*) A change in pump condition, *e.g.*, due to wear or leakage through a relief valve.

(*e*) External leakage, *e.g.*, through a recirculating valve.

(*f*) Change of fuel temperature, which changed the fuel viscosity and hence the internal leakage rate of the pump.

As a result of these departures, it was not certain at any time whether the maximum or minimum designed fuel rate would be available without the necessity for manual adjustment. It was concluded, therefore, that it was operationally undesirable to rely upon the pump characteristic at constant speed to maintain the burners on their designed characteristic.

Dynamic Response Trials

Although there were obviously defects in the system, trials were continued to obtain information regarding its dynamic characteristics. It was soon found that the rate of response of airflow was not fast enough to match the rate of fuel change when maneuvering rapidly. While it was appreciated that the open loop system used for controlling the air would not give the fastest possible response, it was obvious that there were other factors involved. For instance, it was noticed that the fuel-pump speed was departing considerably from its desired value during load changes. It was therefore decided to fit continuous pen recorders to investigate the performance of both the pumps and blowers more fully.

A series of records was taken, using in each case the same load change, making an adjustment to one of the variables in the control system between each run. In this way, optimum settings were quickly found for variables such as proportional band and integral action time of the steam-pressure controller. With these optimum settings applied, the load changes were increased with the object of proving that the ship could carry out, in full automatic control with a clear funnel, the most severe engine movements which might normally be expected. As the severity of the load change was increased, it became obvious from the pen records that the blower r.p.m., which initially started to increase in step with the fuel flow, hesitated and sometimes decreased sharply during the load increase. Due presumably to damping of the instruments, this decrease could not be detected in the blower tachometers. The fall was originally thought to be due to mechanical backlash in the blower control valves, but it eventually became clear that it was associated with a rise in the auxiliary exhaust pressure. This rise was occurring due to the rapid reduction in feeding rate of the boiler caused by the violent rise in burned fuel rate which was taking place early in the load change. When the back-pressure on the blower turbines rose, their available heat drops fell and the blowers slowed down. While nothing could be done immediately to prevent this exhaust pressure rise, which was accentuated by the condenser dump valves being unable to cope with the extra exhaust steam, it was appreciated that changing the steam-pressure controller sensing point from the superheater outlet to the steam drum might improve the situation by making the load change less rapid. On the main-engine throttles being opened, the pressure at superheater outlet was instantaneously reduced owing to the suddenly increased pressure drop across the superheater. Thus abrupt and, in fact, almost step action was taken by the steam-pressure controller to increase the fuel flow to the boiler.

FURTHER TRIALS AND DEVELOPMENT ASHORE

Description of the Admiralty Fuel Experimental Station Test Boiler

The boiler is a modern frigate design of the two-drum type, with superheat temperature controllable by means of dampers, which can restrict or augment the gas flow over the superheater. Registers of the Admiralty Suspended Flame type are fitted. The pneumatic-control system originally fitted to this boiler was similar to that of H.M.S. *Tiger*, although supplied by another manufacturer. It differed, however, in that closed-loop blower control was fitted, with register draft loss being used to meter the air, and the feed regulator was of the three-element pneumatic type. The automatic control of superheat was by pneumatic operation of the dampers. In order to program the air and fuel flow, a measurement of burned fuel flow was required. Since direct measurement of this quantity is not easily achieved in a spill system, the total and spilled flows were measured in flowmeters and were subtracted to

give burned flow. This entailed the subtraction of one large quantity from another of the same order of magnitude and errors inevitably would have resulted; these would have been greatest when the burned flow was least and hence the air/fuel ratio most critical.

Development of the T.B.S. Spill-control System

Until this time, three methods of spill control were common:

(*a*) Constant-speed pump, as in H.M.S. *Tiger*.

(*b*) Constant-supply pressure.

(*c*) Constant-supply/spill pressure differential.

For the wide range systems in H.M. ships, both the latter two methods were impossible. With the atomizers then available, constant differential could not give the required turn-down inside a reasonable pressure range, while the constant-supply pressure system would have required enormous pumps to deliver the large quantities involved in producing low burned flows.

The constant-speed pump had also proved unsatisfactory and a new method of spill control was therefore needed.

Ideally, this was required to be independent of the number of burners in use per pump in order that pumps or boilers could be run parallel when changing over, without manual adjustments to the pump speed being necessary. Furthermore, deviations from the chosen burned flow characteristic were required to be small, in order that the correct air/fuel ratio could be maintained.

To be independent of the number of burners in use, it is evident that whatever quantities relating to the fuel are programmed, these must be common to both pump and burner on the supply side and burner and spill valve on the spill side. The only alternative is a complicated system of dividing measured and programmed quantities by the number of burners in use. The obvious choice is to match the supply and spill pressures, and investigation of not only those fitted in H.M.S. *Tiger* but also other atomizers revealed that it would be possible to use a straight-line relationship between supply and spill pressures, the slope of this line varying according to atomizer size and the turn-down required. The suitable straight line for H.M.S. *Tiger* is shown in Figure 4. To achieve this required relationship, a control system known as T.B.S. was devised, and was tested at the Admiralty Fuel Experimental Station, Haslar. The letters T.B.S. merely stand for the names of the inventors.

Description of the T.B.S. Spill-control System

The T.B.S. spill-control system (Figure 5) consists of two separate pressure-control loops, one for the supply pressure and one for the spill, each loop being fed with the same desired value servo-air signal. The supply pressure is governed by its controller which positions the F.F.O. pump turbine steam valve, so that the output from the supply

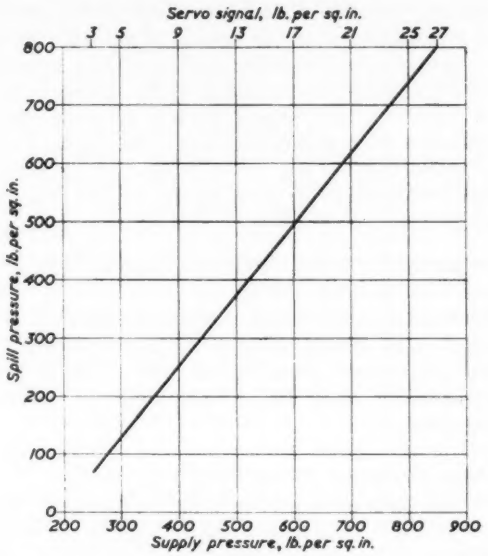


Figure 4. Designed Supply/Spill-pressure Relationship for T.B.S.

pressure transmitter equals the incoming servo signal. Similarly, the spill pressure is governed by its controller, which positions the spill valve so that the output from the spill-pressure transmitter equals the same incoming servo signal. Referring now to Figure 4, it will be seen that if the incoming servo signal is, for example, 15 psi, the supply pressure will control at 550 psi, while the spill pressure controls at 435 psi.

Load-limiting relays are fitted, which prevent the incoming servo signal to the two controllers from exceeding 27 psi or falling below 3 psi. This limits the maximum and minimum controlled pressures and, hence, burned flows.

The incoming signal to the two controllers may either be manually controlled by means of a pressure-reducing valve or be taken from the steam-pressure controller output, when the boiler will be in fully automatic control.

The practical advantages of T.B.S. over the original *Tiger* system are:

(1) The burners remain on their desired characteristic during boiler load changes, thus easing the problem of matching the fuel to the air.

(2) Changing the number of burners in use has no effect upon the output of the others, since the supply and spill pressures are unchanged.

(3) Pump speed is automatically selected for any given boiler power and is automatically compensated for internal or external pump leakage, exhaust-steam pressure changes, fuel viscosity, etc.

(4) Output limiting stops are possible.

(5) A pneumatic signal is now available which is roughly linear with burned flow per register.

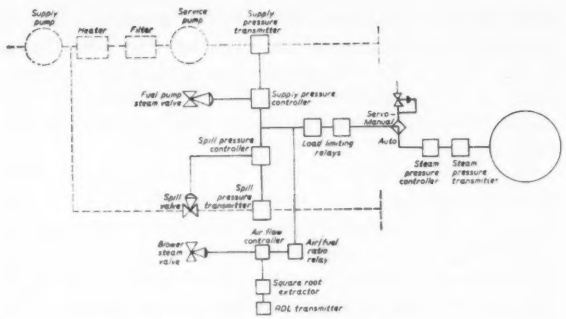


Figure 5. T.B.S. Spill-control System.

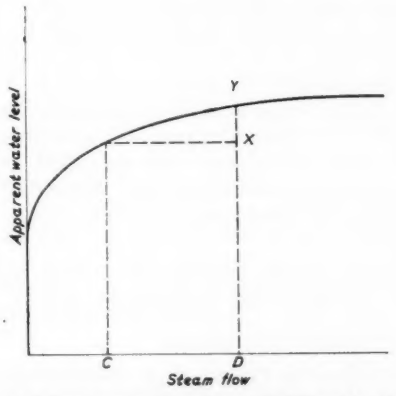


Figure 6. Water-level/Steam-flow Relationship for a Boiler Containing Constant Water Weight.

FEED REGULATION

Development of the "Absolute" Boiler Feed Regulator

Referring to Figure 6, it will be seen that, if a constant weight of water is maintained in the boiler, the apparent water level must rise with increase of load due to the decrease in density of the steam/water mixture. Conversely, if the water level is held constant, as with a conventional single-element regulator, there must be a reduction in the weight of water in the boiler with increase of load. With self-acting regulators of the single-element type, a further reduction in the weight of water occurs due to the proportional action of the regulator. Referring to Figure 7, it will be seen that the shaded area *A* minus shaded area *B* represents the reduction in the weight of water in the boiler which occurs on increase of load. If the feed regulator were, by some means, made to maintain a constant weight of water in the boiler, it follows that feed flow must keep in step with steam flow, as shown in Figure 8.

Consider the imaginary case of an instantaneous change in steam flow from *C* to *D* on Figure 6, even though the water-level regulator may shut the feed valve instantaneously, the weight of water in the boiler after the change in steam flow must equal the weight before the change. Hence, the water level

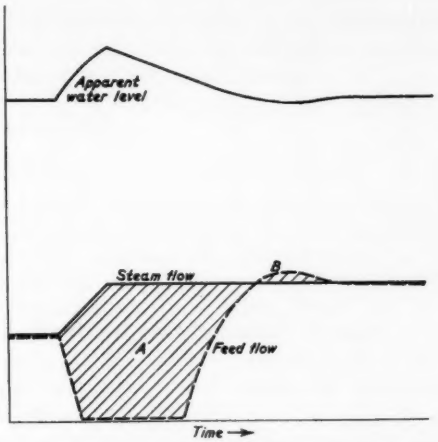


Figure 7. Performance of Single-element Feed Regulator.

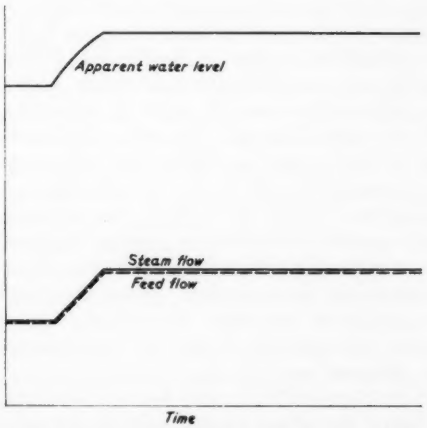


Figure 8. Performance of Constant Water-weight Regulator.

must rise by *XY*. While, in practice, changes in steam flow cannot occur instantaneously, it also takes a positive time for the change in the weight of water to take place, particularly on an increase of power, where the most that the regulator can do is to shut the feed valve. A transient rise in level approximately equal to *XY* must therefore occur on a rapid increase from *C* to *D*, whatever type of feed regulator is fitted.

Consideration of the above led to the suggestion that if a boiler can accept a transient rise in level on sudden increase of power, it should be able to accept this as a programmed level when steady steaming. This could be achieved by a feed regulator sensing water weight rather than apparent level. With such a feed regulator, feed flow should in all circumstances keep in step with steam flow, as shown in Figure 8.

Figure 9 shows diagrammatically the arrangement of the "absolute" feed-water regulator on the test boiler at A.F.E.S. Differential pressure trans-

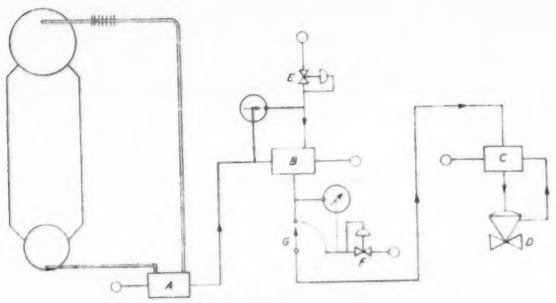


Figure 9. "Absolute" Feed Regulator.

mitter *A* measures the static head of water in the boiler and transmits a pneumatic signal proportional to this static head to controller *B*. Pressure-reducing valve *E* transmits a preset signal linear with the desired value of static head to controller *B*. It can be shown that this static head of water is a function of the weight of water in the boiler. Controller *B* transmits a pneumatic signal to valve positioner *C*, and regulates the opening of feed valve *D*, according to the error between the measured and desired values of static head in the boiler. The proportional band of controller *B* is readily adjustable and integral action can be introduced, if required. Servo manual control of feed-valve position is provided by pressure-reducing valve *F* and selector valve *G*.

Initial trials showed that, when the static head was maintained constant by introducing integral action in the controller, the rise in apparent level which occurred on increase of load could not be accepted in the A.F.E.S. test boiler. The remaining trials were therefore conducted using proportional action only in the controller. The static head was therefore maintained lower at high boiler outputs than at no load, by an amount corresponding to the proportional action of the controller. Various proportional action settings were tried.

DEVELOPMENT OF AN IMPROVED STEAM-PRESSURE CONTROL

The various developments had effected such an improvement in the maneuverability of the boiler as a whole that it was now possible to consider whether an even closer control of steam pressure could be achieved. In H.M.S. *Tiger*, the steam-pressure sensing point was moved from the superheater outlet to the steam drum, because neither the blower control, the spill burner control nor the water-level control was adequate to keep in step with the demands of the steam-pressure controller. With these difficulties overcome, it was decided to try once again controlling steam pressure at the superheater outlet.

Controlling at superheater outlet has the advantage that an instantaneous response is obtained due to the suddenly changed pressure drop through the superheater, whereas with drum sensing, the response is a function of time and of the heat stored in the boiler. The disadvantage is that if the pressure at the superheater outlet is maintained constant, the pressure in the steam drum must rise with load.

It was therefore decided to test a proportional-only system, in which the transmitter output is led direct to the fuel-flow control system T.B.S. and the calibration of the transmitter is arranged to give the superheater-outlet pressure characteristic shown in Figure 10. The resultant steam drum pressure for the A.F.E.S. test boiler is also shown in Figure 10, and it will be seen that the maximum steam drum pressure drop is 12½ psi.

This type of steam pressure control has two advantages, *viz.*:

(*a*) Simplicity.

(*b*) Steady conditions are achieved almost immediately the change in steam flow is complete.

Both these advantages are extremely important in naval boiler installations and the initial trials of this system are promising.

APPLICITION OF THE LESSONS LEARNED TO THE DESIGN OF A NEW CONTROL SYSTEM

Lack of Design Information

Inevitably, the design of a control system must proceed concurrently with the design of the plant if a properly integrated whole is to be achieved. The control-system design must, therefore, be based on past experience of similar plant performance rather than a full knowledge of all the component characteristics, since these are also in the design stage. Furthermore, one must accept that the control system may influence the design of the plant. It may be true to say that any system can be controlled, but heavy penalties in performance and control-system complexity will frequently result if this policy is adopted.

Fortunately, because of the versatility and wide ranges of adjustment of the many excellent pneumatic instruments commercially available, the lack

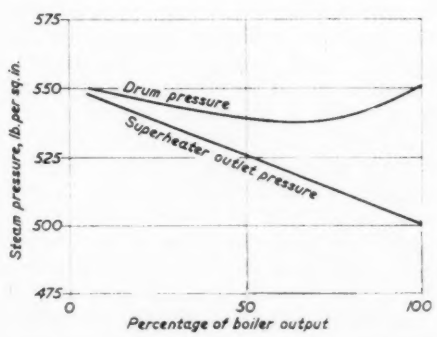


Figure 10. Performance of Proportional Steam-pressure Control.

of knowledge which would permit controller settings to be computed is seldom an embarrassment.

Selection of Controlled Variables

In the early stages of the design, it is essential to give very careful consideration to which of the many plant variables must be controlled, and to the exact means by which they may be controlled. It is, for example, seldom acceptable to program a valve position in order to achieve a desired pressure, since the pressure is a function of not only valve position, but also pressure at valve inlet and fluid viscosity. It is preferable to measure the actual value of the controlled variable and to feed this back to the controller, which will continue to adjust the valve position while there remains an error between desired and actual values of the controlled variable. Thus, in the case of an automatic combustion system, it is preferable to program air and fuel flow per register, which are the two variables primarily deciding the quality of combustion, rather than blower steam and spill-valve positions. Similarly, to achieve optimum plant performance, it is essential that all variables, which have a significant effect upon plant performance, are controlled in such a way that there is no undesirable reaction upon other system components.

Stability

When the development of the fully automatic installation was in its early stages, it was thought that instability and interaction between the various control systems might be major problems, and that a fundamental investigation of plant characteristics would be essential to the development of an inherently stable boiler control. In fact, few stability problems have been encountered, and none of them has required more than simple, on the spot, investigation and deduction to solve them. In many cases it has been found unnecessary and even undesirable to tune loops as tightly as possible.

Care is, however, necessary in the design stage in matters of detail.

Control Valves

Automatic control systems demand valves specifically designed for control. The use of sequential nozzle valves, for example, for controlling a steam turbine cannot give the smooth and consistent response of a single control valve, which can be flow characterized.

Similarly, it is seldom acceptable to adapt for automatic control a valve originally designed for manual operation.

CONCLUSIONS

The problems encountered in the initial sea trials of H.M.S. *Tiger* have been described in some detail in order to provide a background for the explanation of the ensuing developments. In reading of these difficulties, it must be remembered that this was the first fully-automatic wide-range boiler installation at sea in one of H.M. ships, and initial troubles were, therefore, to be expected.

The developments made possible by these initial trials have produced an extremely flexible boiler plant, it now being possible to increase from standby load to full power and achieve the new steady conditions within a period of a few seconds, without hazard to the boiler and with the boiler-room unattended.

Further development needs to be directed towards simplification, thereby making the controls even more reliable and more readily understood by their operators. The authors consider that a fully-automatic wide-range system using simple, self-acting controls is by no means impossible.

dorn
Navy Electrical Equipment
Supplies Since 1939
DORN EQUIPMENT CORP.

* NYLON STUFFING TUBES
(Terminal Type)
* NEOPRENE AND SILICONE PACKINGS
* MOLDED RECEPTACLES AND PLUGS
* RISER TERMINAL BOARDS

27 UPHAM STREET, MELROSE 76, MASS.

DE LAVAL

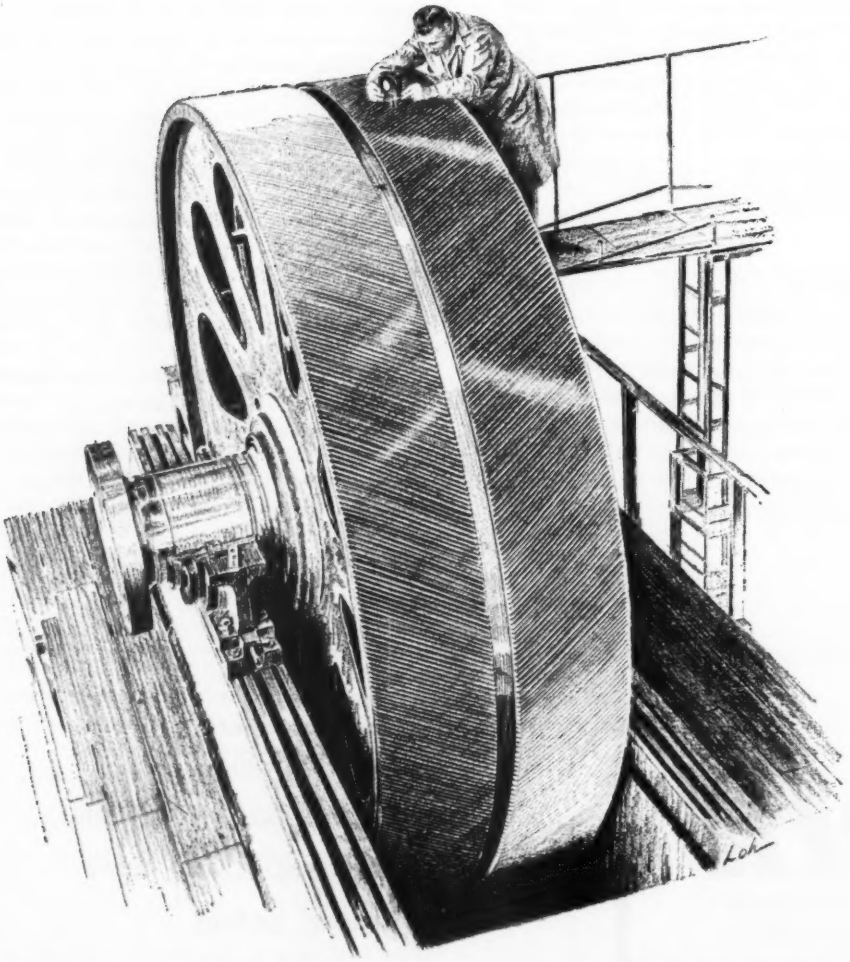
engineered dependability provides vital "muscles" for American shipping

This 14-foot bull gear is part of a De Laval main propulsion unit for a new merchant ship. To meet De Laval precision requirements, the more than 500 teeth around its circumference must be spaced to tolerances better than the industry standard of .0002 in. Gears are hobbed in special air-conditioned rooms with complete temperature regulation.

These and other painstaking manufacturing methods, together with the most exacting quality control procedures, stand behind the engineered dependability that has made De Laval a leading merchant marine and naval supplier.

You can count on the same precise De Laval manufacturing standards . . . the same engineered dependability . . . on all the products De Laval supplies to industry.

De Laval Steam Turbine Company, Trenton 2, N. J.



MG-DL-1054

DE LAVAL • 60 YEARS OF CREATIVITY AND QUALITY

CENTRIFUGAL PUMPS AND COMPRESSORS • TURBINES • IMO® ROTARY PUMPS AND HYDRAULIC MOTORS
MARINE PROPULSION AND AUXILIARY EQUIPMENT • HELICAL AND EPICYCLIC GEARS • TURBOCHARGERS

INST. MAR. ENG. (CAN. DIV.)

EXPERIENCE WITH HARDENED AND GROUND GEARING IN THE ROYAL CANADIAN NAVY

ACKNOWLEDGMENT

This article was written by D. K. Nicholson, Head Power Transmission Section, Department of Director General Ships, Headquarters, Royal Canadian Navy, Ottawa. It appeared in Transactions of The Institute of Marine Engineers (Canadian Division Supplement) of June, 1961, from which it is reprinted. Space prohibits inclusion of the excellent and comprehensive discussion of the paper and many photographs which the interested reader may find in the original publication.

INTRODUCTION

THE INTERNATIONAL CONFERENCE on Gearing held in London by the Institution of Mechanical Engineers in 1958, focused attention on developments affecting all aspects of gearing design, manufacture and lubrication, over a wide range of applications. It was, however, in the marine gearing field that some of the most significant advances in gear design and load-carrying capacity were reported [1, 2] and this was primarily the result of extensive development and test programs initiated by the Admiralty over the previous decade. Substantial advancements in naval propulsion machinery demanded increases in main reduction gearing load-carrying capacity which were clearly unobtainable with hobbed and shaved or soft gearing. While the high load-carrying capacity provided by case-hardened and ground gearing was well known in the general engineering field, very little experience was available even after World War II regarding its application in high power marine machinery installations. Admiralty sponsored gear investigation, development and test programs have since done much to determine many of the design and manufacturing limitations [3, 4] of case-hardened and ground gearing.

The Royal Canadian Navy has been privileged to benefit considerably from the gearing work undertaken by the Admiralty and has in consequence been able to install hardened and ground main reduction gearing in each of its fourteen 30,000 s.h.p. *St. Laurent* Class destroyer escorts now in commission. Experience with these gear units has been unique in that they are believed to have the highest rated tooth loadings of any main turbine reduction gearing in service, and are also the first large ma-

rine gears to be fully carburized and hardened. The most outstanding aspect of this program, however, is that eleven of the shipsets of gearing were manufactured in a newly established Crown-owned gear plant in Canada, thus bringing the Royal Canadian Navy into closer touch with the problems of manufacture than most marine gearing customers either experience or desire.

The scope of this paper will therefore be to review the considerations affecting the choice of hardened and ground main gearing and to present those aspects of manufacture, testing and service experience which may permit a more rational assessment of the general mercantile application of this type of gearing.

CONSIDERATIONS INFLUENCING THE CHOICE OF HARDENED AND GROUND GEARING

The requirement for maximum reliability at minimum cost applies equally well to all items of naval and mercantile machinery alike. Apart from the considerations of bearing design and lubrication, which it is not proposed to cover in this paper, main gearing reliability is largely determined by the margin provided by the gear tooth design with respect to:

a) bending strength—resistance to fracture
b) surface loading—resistance to pitting
c) heat dissipation—resistance to scuffing

Cost is determined by the manufacturing implications of the design requirements and the availability of the necessary production facilities.

For most naval gearing installations, and particularly in classes of the *St. Laurent* type, minimum weight and space is considered to be a requirement which is surpassed in importance only by that of reliability. Unlike mercantile practice, naval gearing is operated at its maximum rated power for only a small percentage of its total life and may well be operated at as low as 10 per cent power for over 80 per cent of its life. It is therefore possible to permit higher design loadings than are acceptable in normal mercantile practice.

Tooth loadings can be increased only to within the limitations of the root and surface strength as determined by the material properties. Providing the teeth are large enough to provide adequate root strength, the load-carrying capacity of soft gears is limited by the fatigue strength of the material under compressive loading. Surface fatigue strength increases directly with the ultimate tensile strength, which in turn is proportional to the surface hardness. The maximum tooth loading which can be transmitted by gearing which is finished by hobbing and shaving is therefore determined by the maximum surface hardness which it is practicable to machine. This limiting hardness is generally accepted to be about 350 B.H.N and is obtained by through hardening high percentage alloy steels. In mercantile gearing installations the Lloyd's K factor for tooth loading would be limited to about 120 K for a material of this hardness, but a peak design loading of up to 250 K might be permissible in a naval gear installation.

A considerable increase of surface fatigue strength and load-carrying capacity is provided by case-hardening the gear teeth, in fact the load-carrying capacity is then no longer limited by the surface fatigue strength. The design loading criterion for case-hardened gears is now recognized [2] as usually being the root strength since the bending fatigue strength, unlike the surface fatigue strength, does not increase with the ultimate tensile strength of the material. The utilization of the high surface load-carrying capacity provided by case-hardened gears depends entirely on the tooth design. In general it is found that a case-hardened gear will permit at least two and a half times the maximum root stress allowable in a hobbed and shaved gear of the same tooth design.

The root strength of carburized and hardened gears is greatly assisted by the compressive stresses created in the hardened layer due to the increased volume of material caused by the formation of martensite. This compressive stress must first be absorbed by the external tooth loading before the tooth roots are subjected to the normal tensile bending stresses. The tooth strength is thereby increased over and above the strength of the hardened case. It should be noted that surface residual compressive stress is not obtained with induction hardened gears.

The third factor influencing reliability is the resistance to scuffing which relates to the ability of a tooth surface to maintain an oil film under pressure and under sliding. The scuffing limit in soft gearing is generally above the surface fatigue limit but, as the surface hardness increases the load-carrying criterion, other than root strength, changes from surface pitting to scuffing. The avoidance of scuffing in hardened and ground gearing is generally a matter of obtaining a tooth design which produces the minimum of sliding and which has a good surface finish.

On the basis of presently accepted design limits the foregoing indicates that the highest degree of reliability and freedom from failure is obtainable from case-hardened and ground gearing.

An important milestone in establishing the value of hardened and ground gearing in naval machinery was the installation of two 27,000 s.h.p. units in H.M.S. *Diana* in 1951. These gears, which were built in Switzerland, were of the double reduction, dual articulated type and were carburized and hardened with the exception of the air-hardened secondary reduction gearwheels. The tooth loadings were up to 260 K in the H.P. primary reduction and 200 K in the secondary reduction. The satisfactory experience obtained with the *Diana* gearing did much to influence the type and design of gearing selected for the *St. Laurent* Class.

The availability of domestic manufacturing facilities is a matter of prime concern in specifying naval main gearing requirements, as indeed for any defense equipment. It was such a consideration which faced the Royal Canadian Navy when it embarked on a destroyer escort program in 1950 with the technical assistance of the Admiralty. The requirement was for all machinery to be manufactured in Canada other than the initial sets, which were to be built and tested by the designers. There being no manufacturing source of precision marine reduction gearing in Canada at all, the Canadian Government decided to establish a Crown-owned gear plant in Montreal to be operated under contract by a commercial engineering company to produce naval gearing. It was thus possible to select a type and design of gearing best suited to the naval requirement and then to set up the necessary facilities to manufacture on a production basis.

The circumstances regarding the selection of hardened and ground gearing for the *St. Laurent* Class are perhaps rather unique, since the Royal Canadian Navy was not only accepting a most advanced gear design having tooth loadings appreciably higher than the *Diana* gearing for installation in an entire class of ships, but it was also committed to arranging for their manufacture in the first gear plant of its type in the world, involving a type of work, techniques and processes which were completely outside all previous experience in North America.

St. Laurent CLASS MAIN GEARING DESIGN

The *St. Laurent* Class main gearing design (Figures 1 and 2) is of the double reduction dual tandem articulated single helical type incorporating a triple reduction cruising turbine drive. Each unit transmits 15,000 s.h.p. All pinions and gearwheels are carburized, hardened and ground. Details of the original gear design and materials for the main turbine drive are given in Tables I and II respectively.

PAMETRADA SHORE TRIALS

In 1951 the port unit of the first shipset of gearing was sent to Pametrada for full power testing under a dynamometer load in conjunction with the complete main and auxiliary machinery installation. The gearcase was installed on simulated engine room seatings and on a three point support. The three chocking areas are shown by the double hatching in Figure 3 (a).

Using an extreme pressure oil, in accordance with the current Admiralty running-in practice, the gearing was gradually run up to about 94 per cent full power when overheating occurred in the secondary reduction gearwheel forward bearing. The condition of the gearing was excellent, but it was decided that further trials were necessary to prove the ability of the gearing to run on standard turbine oil OM88, which had been specified for

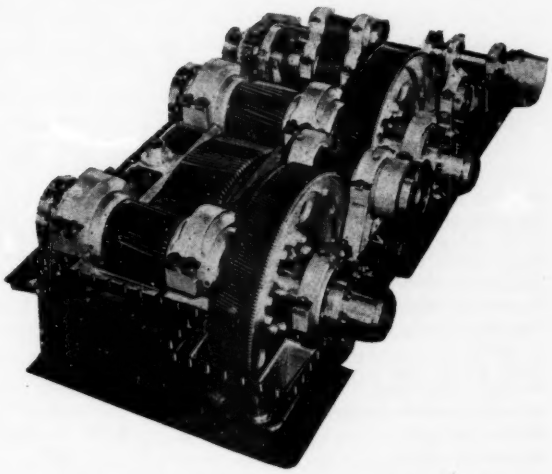
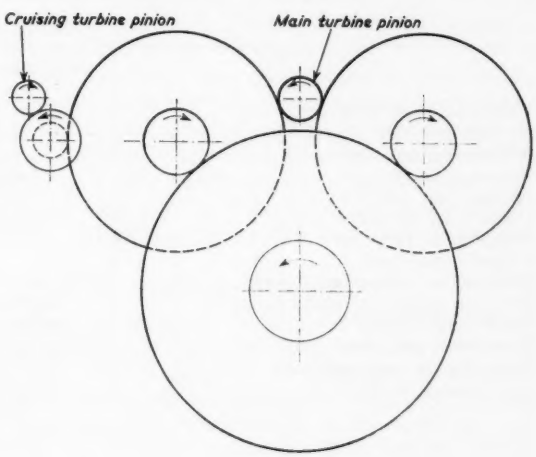


Figure 1. St. Laurent Class main gearing port unit.



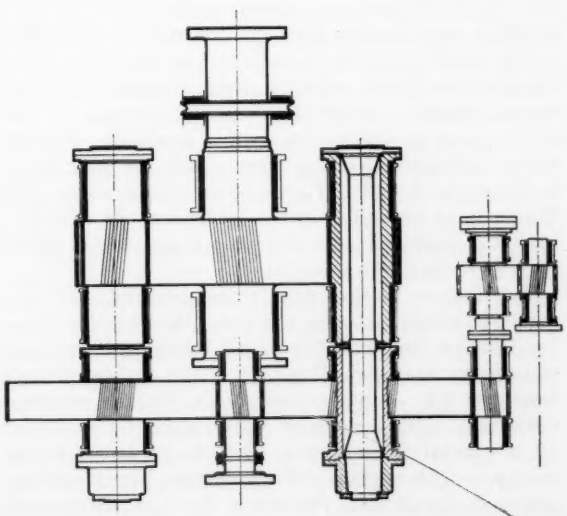


Figure 2. Arrangement of St. Laurent Class Main Gearing.

TABLE I

St. Laurent Class Main Gear Design Data

	Original Design				Revised design			
	Primary		Secondary		Primary		Secondary	
	Pinion	Wheel	Pinion	Wheel	Pinion	Wheel	Pinion	Wheel
Number of elements	1	2	2	1	1	2	2	1
Number of teeth	37	190	29	143	43	221	38	187
Pitch circle diameter, inch	8.98	46.13	13.61	67.10	8.98	46.14	13.63	67.08
Face width, inch	7.875		13.75		7.875		13.75	
Tangential load/inch face width, lb./in.	2402		4664		2406		4666	
Reduction ratio	5.135		4.931		5.140		4.921	
Overall ratio	25.32				25.29			
K factor	320		412		320		412	
Helix angle, deg.	10		6		10		6	
Normal pitch, inch	0.742		1.463		0.640		1.114	
Normal pressure angle, deg.	15		15		23		20	
Addendum, inch	0.241	0.206	0.584	0.347	0.221	0.181	0.377	0.326
Addendum ratio	1.168		1.685		1.224		1.156	

TABLE II—*Gear Material*

	Original material (Swiss)	Modified A.I.S.I. 3310 (D.E.W. 3610)	A.I.S.I. 3110
CHEMICAL COMPOSITION			
Carbon, per cent	0.08	0.08–0.14	0.08–0.13
Manganese, per cent	0.44	0.40–0.60	0.45–0.60
Silicon, per cent	0.25–0.30	0.20–0.35	0.20–0.35
Nickel, per cent	3.20–3.50	3.00–3.25	3.25–3.75
Chromium, per cent	0.54–0.60	0.40–0.60	1.40–1.75
Phosphorus, per cent		0.025 maximum	0.025 maximum
Sulphur, per cent		0.025 maximum	0.025 maximum
MECHANICAL PROPERTIES (CORE)	After water hardening	After water hardening	After oil hardening
Ultimate tensile strength, lb./sq. in.	143,000–163,000	120,000 minimum	120,000 minimum
Yield point, lb./sq. in.	114,000–134,000	85,000 minimum	85,000 minimum
Elongation, per cent	8–10 (on L=10d.)	12 min. (on 2 ins.)	12 min. (on 2 ins.)
Reduction in area, per cent	45 minimum	40 minimum	40 minimum
Izod impact, ft./lbs.	35 minimum	30 minimum	30 minimum

service. At 85 per cent power, with OM88 oil, light scuffing was observed on the secondary reduction pinion tooth tips and at the roots of the main gearwheel. The OM88 oil was then replaced with extreme pressure oil for the remaining trials on this set of gearing. The gear unit was gradually brought up to full power loading after which the gear tooth scuffing was found to have polished over at one end but to have extended at the other end. In addition, both the forward and after main gearwheel bearings were found to have wiped.

The failure of the main wheel bearings led to a series of bearing design changes affecting the angular location and number of oil inlets and the type of backing material. The first of the revised design bearings was tested concurrently with a gearcase deflection test, for which dial indicators mounted on a special frame were used to measure movements of each corner of the gearcase. The measured gearcase distortion, permitted by the three-point support at high powers, was considered to be excessive and consequently a contributory cause of the gear scuffing. It was decided that the after corners of the gearcase should be chocked to reduce the distortion at high powers. Additional torque resisting chocks were fitted under each side of the gearcase, to provide a five-point support as shown in Figure 3(a) by the single and double hatched areas. The gearing subsequently satisfactorily completed a four hour full power proving trial and a short trial under 130 per cent full power torque.

The first gear set completed more than 400 running hours over the full power range during the course of trials designed to prove the entire main and auxiliary machinery installation. The earlier scuffing on these gears was found to have polished over quite satisfactorily after the completion of all the prototype trials.

The ability of this gearing design to run without scuffing on standard turbine oil was rather obscured by the possible effects of the distortion under a three-point support and the wiped main gearwheel

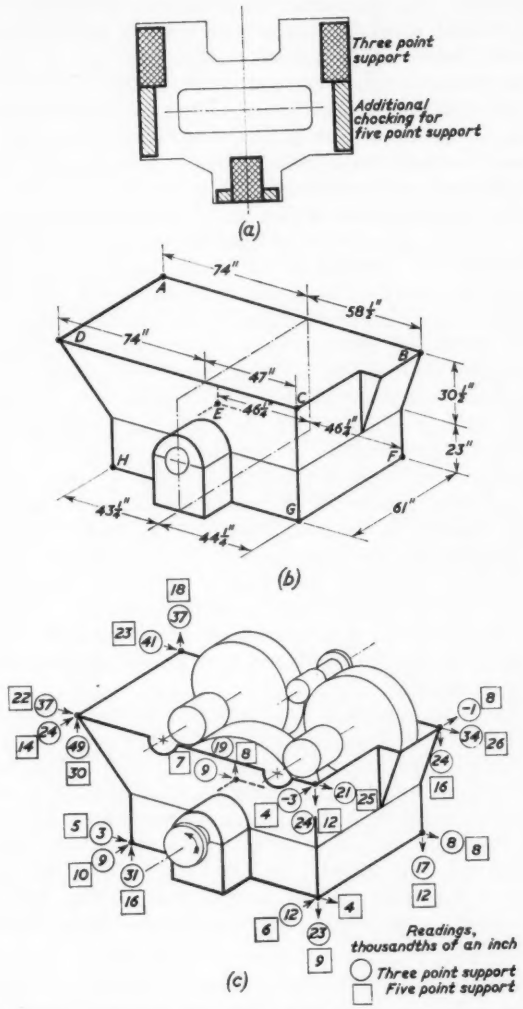


Figure 3. (a)—Gearcase chocking arrangement. (b)—Reference points for measuring gearcase distortions. (c)—Gearcase distortions under 130 per cent full power torque.

bearings. Since this ability could not be conclusively proved on gearing which had in fact already scuffed, it was decided to test the port unit of the second shipset of gearing on standard turbine oil only. The oil selected for these trials was OM100.

After running-in under low power loading for 20 hours the second port unit was worked up to 50 per cent power on a five-point support. Scuffing was observed commencing at the after ends of the secondary reduction pinions. Further increments of loading above the 50 per cent power increased the scuffing until the trial was stopped at 80 per cent power.

It was concluded from the trials on the second unit that the gear design was not capable of operation on standard turbine oil without scuffing. While steps were immediately taken to carry out a design investigation, it was necessary to confirm that this highly loaded gear design was capable of completing all trials up to full power without distress when used only with an extreme pressure oil on a five-point support. The port gearing unit from the third shipset was accordingly sent to Pametrada for testing. All trials including the 130 per cent torque trial were satisfactorily completed by this unit on a five-point support using extreme pressure oil. Since both the second and third unit had been operated on a five-point support and that scuffing had occurred only in the unit running with standard turbine oil, it was decided to test the significance of the different gearcase distortions between the three and five-point methods of support. The third gear unit was subsequently run up to full power on a three-point support without any sign of tooth distress, thus proving that the gear design was capable of being run satisfactorily on either three or five-points providing extreme pressure oil was used. The gearcase distortions which were measured during the trials on the third unit with three and five-point supports are shown in Figures 3 (b) and (c).

It may be noted that the gearing in each of the three units tested at Pametrada have given a completely trouble-free performance in service with no sign of scuffing or any other deleterious effects. The second port unit was returned to the manufacturer for inspection and re-grinding of the scuffed components before the gearing was installed in the ship.

REVISED GEAR DESIGN

Following separate design investigations carried out by the gear manufacturer and the Admiralty Vickers Gearing Research Association, it was concluded that the specific sliding or the slide/roll ratio in approach and recess flanks of the secondary reduction gear teeth were too high for the design tooth loading and peripheral speed. A revised design (Table I) was developed by the manufacturer to permit operation at all powers on standard turbine oil OM100. The design was developed in consideration of scuffing criteria determined by AVGRA from a disc-testing program and involved an increase in pressure angle and diametral pitch.

Although the Pametrada trials produced no scuffing in the primary reduction gear train when running on OM100, the tooth design, when considered on the same basis as the secondary reduction tooth design, was found to be marginal. A revised primary reduction tooth design was therefore developed, again with an increased pressure angle and diametral pitch. As mentioned later, the revised gear design has been entirely satisfactory in service but the 23 degree pressure angle in the primary reduction has been found to cause appreciable difficulty in manufacture. Later gear units in the class have been fitted with the revised secondary reduction gear design but with the original primary reduction design.

CROWN-OWNED GEAR PLANT

The Crown-owned gear plant in Canada was equipped to permit the manufacture of a full range of naval main and auxiliary turbine gearing up to 142 inch diameter, which is the capacity of the largest grinding machines. The gears are cut, ground and inspected on precision equipment installed in a temperature controlled, windowless but well lit shop. The plant includes a separate heat treatment shop in which are installed vertical gas carburizing and reheating furnaces of up to 75 inch diameter capacity. The large gearwheel furnaces are heated by oil fired radiant tubes while the smaller pinion furnace is electrically heated. The atmosphere and carburizing medium in the furnaces are controlled by propane-fed gas generators of the exothermic and endothermic types. A dew-point indicator is used to control the carburizing potential of the gas.

MANUFACTURE IN CANADA

General Design Considerations affecting Manufacture

The high load carrying capacity provided by case-hardened gear teeth is, needless to say, by no means solely dependent on the surface hardness. Research which has so far been carried out in this field points to the significance of the hardness curve between the tooth surface and the core, the type of case and the method of hardening as factors influencing the tooth strength and fatigue resistance to bending. It is apparent that tooth root strength, or resistance to shock loading, decreases as the case depth increases. The bending fatigue strength on the other hand increases with the case depth up to a maximum when the case depth/module ratio reaches a value which is estimated by various researchers as ranging from .07-.23. Effective case depth is the depth of case measured from the surface having a hardness of not less than a certain specified value. The practice in Canada has been to measure effective case depth above the 500 DPH level on the hardness curve.

The consideration which arises is that the case depth must be maintained to within very close limits in order to achieve optimum strength and load-carrying capacity. The process of carburizing and hardening gear rims does inherently involve growth and distortion which must be satisfactorily combated in order to make the process practicable. Excessive gear rim growth and tooth distortion must be removed by grinding, and it is not only necessary to keep grinding stock down to a minimum in the interest of reasonable manufacturing time, but there is also a very definite limit on the amount by which the case can be reduced. In addition to the consideration of maintaining a minimum depth of case, any growth or shrinkage of the gear rim affecting the design outside diameter may also affect the addendum ratio to the point of reducing the active profiles of the mating teeth. Gearwheel addendum changes with the growth or shrinkage of the wheel diameter; thus an oversize gear wheel would have an increased addendum and would necessitate an offsetting reduction in the addendum of the mating pinion. This would result in increased sliding on both the pinion and wheel approach flanks, which could well reduce the resistance to scuffing to a critical level.

The manufacture of hardened and ground gearing will be seen to hinge entirely on the ability to manufacture gearwheels to a high degree of accuracy with a surface hardness and case depth each to within closely prescribed limits. The manufacture of case hardened pinions does not involve the same extent of unpredictable dimensional variations during heat treatment as the gear wheels. The distortions and growths which do occur are sufficiently small or predictable to permit the pinion to be manufactured to suit the finished gear wheels.

It may therefore be of interest to note the principal aspects of the manufacturing procedure used in Canada for the manufacture of the primary and secondary reduction gear wheels for the *St. Laurent* Class main gearing, with a view to providing a basis for assessing the manufacturing problems and economics of marine hardened and ground main propulsion gearing.

The requirement is to produce accurately ground gear wheels and pinions having tooth surface hardnesses ranging from 62 Rockwell C (739 DPH) on the pinion teeth to 59 Rockwell C (675 DPH) on the gear teeth with a minimum acceptable value of 57 Rockwell C (636 DPH). The depth of case measured with respect to 500 DPH is required to be not less than .040 in. and to have a fine grain tempered martensitic micro-structure free from boundary carbides.

Material

In order that the gearwheels may be finish ground as close as possible to the required design dimensions, with the minimum removal of stock, it is necessary that the material be selected not only for its hardenability and provision of a ductile core, but also for its stability and predictable behavior under heat treatment. The overall properties of the material used in the original Swiss-made gearing for the *St. Laurent* Class program—a low carbon nickel chrome water-quenching steel—have been hard to match in comparable steels available in North America. The specified composition and properties of this material, which are given in Table II were most closely matched by using a modified AISI 3310 carburizing steel which has been designated as DEW 3610. Forgings of this material, which has been used for the majority of pinions and wheels manufactured to date, have not permitted the degree of dimensional control considered desirable during heat treatment, there even being a significant variation between forgings of the same heat. This experience is now known to be largely

due to the inadequate restriction of grain size in the forgings. Recent experience has been with AISI 3310, a standard oil-quenching steel which minimizes the risk of cracking generally associated with water-quenching steels. It is believed that AISI 3310 should reduce distortions but experience with this material has not been sufficiently extensive to date to judge the degree of improvement. The heat treatment described in this paper is that which is currently in use for AISI 3310.

Pre-quenching

The amount that a carburized gear rim will grow in diameter during hardening may vary considerably from forging to forging even where they are from the same heat. To provide a reasonable indication of how much this growth may be, the gear rims are first subjected to a pre-quenching in the condition as received from the forging supplier. AISI 3310 rims are heated to 1,480 deg. F. and held for four hours. The rim is quenched in oil at 120/150 deg. F. and allowed to cool to shop temperature. DEW 3610 gear rims are heated to 1,500 deg. F and quenched in a 5 per cent caustic soda solution.

Gear Cutting

Gear rims are machined to an outside diameter, prior to gear cutting and carburizing, which makes allowance for the subsequent removal of the carburized case on the tips of the teeth, for a slight shrinkage during carburizing and for the anticipated growth during hardening as determined from the pre-quench. The pre-quenching increases the hardness of the material to the detriment of its machinability, but subsequent annealing has been necessary in only a few instances and only with DEW 3610 material. The gear teeth are cut on rack shaping machines in three principal operations; roughing, finishing and protuberance cutting. Protuberance cutters are used to form the tooth roots and to confine the grinding stock allowance to the tooth flanks.

Carburizing

The gear rim and the control test pieces, which are tooled out of the rim bore, are heated in the carburizing furnace to 1,650 deg. F in an inert gas atmosphere which is passed at the rate of approximately 1,000 cu ft/hr. Up to about 3 per cent propane is added to the neutral carrier gas at the commencement of carburizing and is reduced to about ¼ per cent during the subsequent diffusion. Test pieces are removed from the furnace periodically to check the case depth by penetrascope. Previous practice has been to continue the carburizing until about half the required case depth was indicated on the test piece and then to diffuse until the test piece indicated the required case and an absence of boundary carbides. A modified carburizing procedure is now in use, involving alternate two hour cycles for carburizing and diffusion, which is

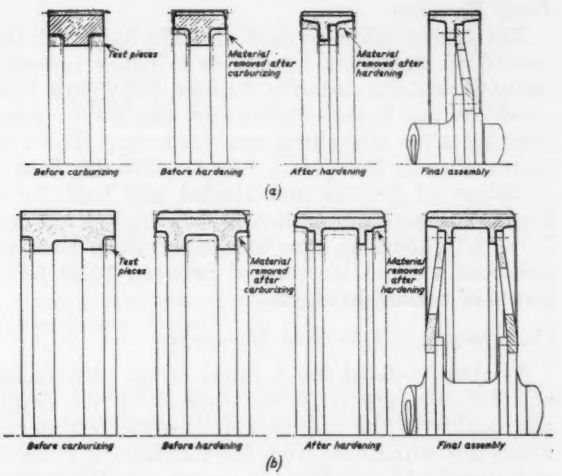


Figure 4. (a)—Primary reduction gear rim sections up to assembly. (b)—Secondary reduction gear rim sections up to assembly.

believed to reduce the presence of free cementite. Secondary reduction gearwheels were carburized for about 18 hours and diffused for a further 18 hours.

After cooling in a tempering furnace the gear rims are stress-relieved or annealed by holding at 1,200 deg. F for five to six hours and then cooling in the furnace to below 600 deg. F. The gear rim distortion which is produced during carburizing is corrected as far as possible before proceding with further machining. Out of roundness and tapering (conicality) are corrected by applying a jacking spider which uses large radiused pads to stretch the rim. Out of flatness is corrected on a large press. The carburized layer is then machined off all surfaces not required to be case hardened (Figure 4).

Hardening

The temperature of the gear rim and its test pieces is raised to 1,200 deg. F and held for 6 hours and then raised to 1,480 deg. F and held for 2 to 4 hours. The gear rim is then quickly transferred from the furnace to a quenching fixture which consists of a heavy cast steel ring fitted with a series of clamps and adjustable taper pads arranged circumferentially and set to a predetermined diameter. The taper pads are arranged to locate the bore of the rim while the clamps hold the rim flat. The gear rim complete with the quenching fixture is quenched in oil at 120/150 deg F and held in the oil for 20 minutes. The time taken between emerging from the furnace to quenching is approximately 3½ minutes which includes a 2 minute holding period on the quenching fixture. Following hardening, the gear rim is tempered at 250 deg F for 8 to 10 hours after which it is removed from the quenching fixture.

Deep Freezing

The higher alloy content of AISI 3310 and the use of oil quenching introduces a higher susceptibility to retained austenite than did DEW 3610. This condition has been satisfactorily avoided by deep freezing after quenching and tempering. The rim temperature is lowered to −90 to −100 deg F in a container of dry ice and alcohol and held for 2 hours. The gear rim is then re-tempered at 250 deg F for 8-10 hours as after hardening. Deep freezing produces a slight increase of between 10-20 DPH points of surface hardness.

Case Depth and Surface Hardness

As already stated the duration of the carburizing and diffusion process is determined by the depth and quality of the case obtained on the test pieces which are withdrawn from the carburizing furnace and quenched in oil. The test pieces, which measure 1½in. × 1½in. × 1½in. receive a more severe quench than the gear rims principally on account of the effect of the different masses. The result is that the case hardnesses measured on the test pieces are appreciably higher than on the corresponding gear rim which is subjected to the same heat treatment. For similar reasons the surface hardness obtained in pinions is slightly higher than on the gearwheels. Case depths which are determined from the hardness curves tend to be only slightly higher on test pieces than on the corresponding gear teeth. The depth of case formed round the gear tooth roots is generally found to be slightly less than that on the gear flanks due to the effect of surface concavity. This effect is not considered undesirable since the subsequent grinding operations on the tooth flanks tend to unify the depth of case round the entire tooth. The required case depths are determined in consideration of grinding stock allowances which must be provided to produce the finish ground tooth profiles. The required test piece case depths are given in Table III together with the corresponding surface hardness values.

TABLE III

Test Piece Case Depths and Surface Hardness

	Case depth inches	Surface hardness DPH(5Kg) Rc
Pinions	0.050–0.070	820–942 65–68
Primary gearwheels	0.050–0.070	763–820 63–65
Secondary gearwheels ...	0.075–0.100	763–820 63–65

Gear rims which have been sectioned have clearly illustrated the difference in case properties between the production test pieces and the actual gear. Figure 5 shows the mean tooth flank and tooth root hardness curves measured from a sectioned DEW 3610 primary reduction gear rim, from which approximately .016 in. of grinding stock had been removed, together with the hardness curve for the corresponding test piece. The gear tooth hardness

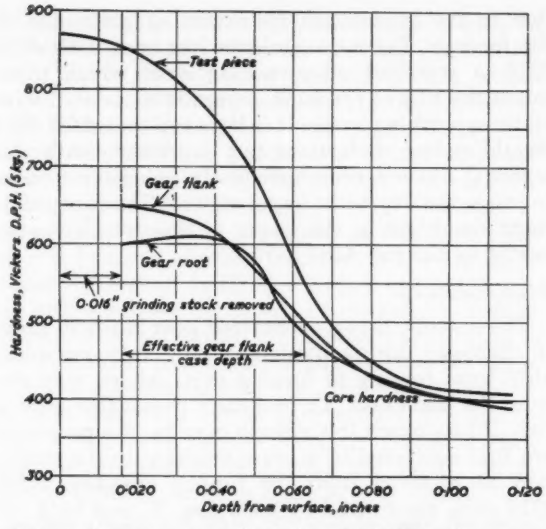


Figure 5. Hardness gradients for DEW 3610 primary gear rim.

curves were derived from two diametrically opposite gear rim teeth each of which was sectioned in three locations across the tooth face.

	Test piece	Gear flank	Gear root
Surface hardness D.H.P. ..	870	650	600
Case depth inches (500 D.P.H.)	0.069	0.047	0.044
Visual case depth inches ..	0.056–0.060	0.052	0.052

Gear Rim Distortion

The straightening operations carried out after carburizing are repeated after hardening. The trueness and roundness of the gear rims are carefully checked before the bores are machined to receive the gear wheel discs which are assembled with a small shrink fit.

The amount by which the gear rim diameters shrink during carburizing is usually less than the growth during hardening which in the case of the 67 inch secondary reduction gear were recorded as high as .160 inches. This results in a net increase of the tooth root diameter between the cutting and hardening stages. Since the tooth roots are not ground except for blending-in the finish-ground tooth flanks it is most important that the final root diameter does not vary appreciably from the design figure. In practice it has been possible to hold the final diameter to within +.030 inches on the primary wheels and +.070 inches on the secondary wheel of the design figures. The outside diameter of the gear rim, which is machined after carburizing and ground after hardening, does not usually vary as much as the root diameter. Variations in outside diameters do, of course, raise a special problem when manufacturing locked trains where it is necessary to obtain pairs of gearwheels of the same dimensions. In dealing with a number of gear units it

is possible to select matching pairs of gear rims. Where the size of the gear rim after carburizing indicates that it would be too large after completing the full heat treatment, it has been satisfactory to re-cut and recarburize the gear rims with no detrimental effect to the case or core properties.

Out of roundness in the gear rims after heat treatment has been recorded up to .070 inches for primary wheels and up to .100 inches for secondary wheels. The out of roundness in the majority of gear rims was found to be about half these values prior to being corrected to within .020 inches of the true diameter. Out of flatness is a much smaller problem and is in fact corrected to within .010 inches in most gear rims before machining.

Gear Grinding

The case-hardened gears are ground using the Maag grinding process which utilizes the fundamental principle of involute generation by rolling gear teeth over the cutting edges of accurately located dished grinding wheels. The method of applying this principle at the Canadian gear plant is different for pinions and gearwheels. The generating method used for gearwheel grinding requires the two grinding wheels to be set with the grinding planes, formed by the outer edges, inclined to match the flanks of the basic rack cutter Figure 6(a). The true involute tooth profile is obtained by the relative rolling or traversing of the grinding wheels acting as a rack cutter about the pitch circle diameter of the gearwheel, thus simultaneously generating the ahead and astern flanks of two separate teeth. The pressure angle of the tooth profiles generated by this process is determined entirely by the inclination of setting of the two grinding planes. The arc of grinding wheel contact with the tooth flanks is small but nevertheless sufficient to produce the characteristic criss-cross grinding arc pattern of this process.

The pinions are ground on machines where the involute profile is generated from the base circle using what is known as the zero degree method. The two grinding wheels are arranged with the grinding planes parallel and face inwards (Figure 6(b)). The bottom tips of the grinding wheels are set to touch the outside flanks of a suitable small block of teeth on a plane tangential with the base circle, about which the pinion is then rolled and traversed. The pressure angle of the tooth is determined by the base circle diameter and the accuracy of the involute profile is primarily dependent on the setting of the grinding wheel tips with respect to the base circle. The point contact of the grinding wheel in this method permits an exceptionally fine surface finish which is devoid of the criss-cross grinding pattern obtained on the gearwheel teeth. The most important advantage of zero degree grinding is that it permits the most satisfactory method of accurately applying tooth profile corrections. Tip and root

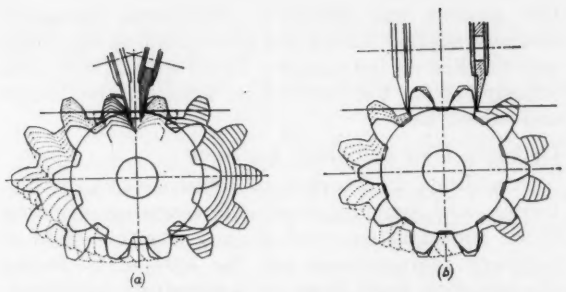


Figure 6. (a)—Inclined wheel grinding method. (b)—Zero degree grinding method.

relief is applied to the pinion flanks by an additional movement being imparted to the pinion at the end of each generating stroke by a cam-actuated mechanism.

Gear grinding is carried out in the three broad phases of roughing, semi-finishing and finishing. The roughing operation is essentially one of removing the minimum stock necessary to clean up all tooth flanks and must be preceded by careful setting up and followed through with appropriate adjustments to the grinding heads. The stock removed per pass is reduced from about .002 inches during rough-grinding to about .0005 inches during the semi-finishing operation when the tooth profiles and pitch spacing are brought close to the required accuracy. The grinding wheel generating speed is reduced during semi-finishing and is reduced appreciably further during the finish-grinding operation which is allowed to continue until the wheels, which are set to remove no more than .0001 to .0002 inches of stock, "spark out." The limitation on the amount by which the original case depth, as indicated by the test pieces, may be reduced during grinding is presently accepted by the Royal Canadian Navy as 30 per cent, and is measured from the point on the gear where the grinding wheels first make contact. This is of course an arbitrary limitation but experience has shown it to be realistic and in line with the specified requirement for final surface hardness and case depth.

The gearwheels are usually completely finish-ground before manufacture is commenced on the mating pinions. The diameters to which the pinions are machined prior to gear cutting and the tooth block M measurement are determined to suit the finished gearwheel. The pinions are ground to match the respective wheels exactly by obtaining the same base pitch measurements and by appropriate adjustments following numerous checks in the meshing frame. The pinions are ground to obtain full depth meshing over the entire length of tooth with the axes of the pinion and wheel parallel. Contrary to present thinking, helix angle correction has been applied to all existing units. A torque correction of .0004 inches on the primary and secondary reduc-

tion pinions was originally considered necessary and was applied during the final grinding operation and checked on the meshing frame with a .0004 inch adjustment on the parallelism between the pinion and wheel axes.

Grinding Time and Gear Accuracy

In addition to the obvious influence of gear distortion and grinding stock allowance on grinding times, consideration must be given to the effect of accuracy requirements and the ease of achieving the specified tooth form as determined by limitations of the manufacturing equipment. The accuracy specified for the gears made in Canada together with the average values of grinding stock removed and total grinding hours are shown in Table IV.

TABLE IV

Gear Accuracies and Grinding Times

	Pinions	Primary reduction gearwheels (46 in. PCD)	Secondary reduction gearwheels (67 in. PCD)
Maximum profile errors, inches	.00015	.00015	.00015
Maximum tooth spacing errors, inches	.00015	.00025	.00035
Average stock removed per flank, inches	008-015	.010-.021	.012-.030
Average grinding time, hours	65-90 160 (15 deg. P.A.) 250 (23 deg. P.A.)		400

The grinding hours which are inclusive of setting-up times and all checking time between grinding operations, reflect a marked increase between the primary reduction gearwheels of the 15 deg and 23 deg pressure angle designs. It will be seen from Figure 6(a) that with a smaller tooth and a higher pressure angle, the tips of the two grinding wheels would have to be thinned in order to extend to the bottom of each tooth flank without interference. The necessary thinning produces flexibility which in turn appreciably lengthens the grinding time, to achieve a given accuracy. The grinding wheels are of course the key between grinding time and accuracy in this process. Since the grinding wheels are in contact with the gear flanks only at one point, or a small arc on the fine dished edge, the requirement for stability and good uniform cutting qualities is critical. The inability of either a single wheel or both wheels to retain uniform cutting properties quickly increases the time required to produce a given accuracy. The degree of gearwheel flexibility is affected by the amount of edge contact with the tooth surface and will consequently vary as the arc contact of the inclined grinding wheel method changes at tooth entry and exit. This variation in grinding wheel flexibility is not so evident with the zero degree grinding method where the variation in edge contact is much less throughout the entire generating and traversing cycle. Early experience showed that grinding times could be influenced far more by the type of grinding wheel than by the amount of grinding stock to be removed. Flexibility and loss of cutting qualities in grinding wheels will extensively prolong the time required to correct very minor deviations from the required profile. Stiffening plates may be used to combat flexibility but will easily give rise to serious grinding burns where the grinding wheel flexure is due to poor cutting qualities.

The problem of grinding wheel flexibility and poor cutting qualities came to a head during the manufacture of the 23 deg pressure angle primary reduction gearwheels. The Canadian grinding wheel industry was consulted and after considerable experimentation with various grits, grain structures and bonds, a superior grinding wheel was eventually developed which combined all the desirable requirements of uniformity and consistency in cutting properties and strength. Furthermore, the wheels were found to be sufficiently versatile regarding cutting properties and grinding finish to be used for both roughing and finishing operations. It was thus found possible to produce the 23 deg pressure angle tooth form to the required standard of accuracy, but only at the expense of increased grinding time as shown in Table IV.

The permitted tooth spacing errors will be noted to be slightly outside the values specified for British Standard 1807 Class A1 which is generally applicable to hobbed and shaved gearing and is indeed necessary for most marine steam turbine reduction gearing of this type. Class A1 accuracy is in fact achieved in the Canadian gear plant but there is no evidence to suggest that it is necessary for hardened and ground gearing except for the most stringent of naval requirements relating to quietness of operation. Higher accuracies mean extending the selective grinding operations during the finishing process.

Assembly and Shop Testing

The mating sets of pinions and gearwheels are assembled in gearcases having all bearing housings bored and scraped to ensure parallelism between the axes. Gearcase parallelism between axes is a naval requirement to permit the use of interchangeable concentric bearings. Non-clearance concentric bearings are used for checking the meshing alignment of the pinions and gearwheels in the gearcase. For correct alignment the mating patterns registered with non-clearance bearings are required to compare with the mating patterns obtained on the meshing frame. The dual drives between the primary and secondary reduction gear trains are assembled and locked in a manner to ensure that all ahead flanks are simultaneously in contact at all powers. It is required that any variation between quill shaft torques, due to changing journal attitudes at low power, is never sufficient to cause tooth separation.

Each gearcase is mounted on the basic three-point

support during manufacture and assembly on the test bed. A check on the condition of the gearcase from the time of assembly to the ship installation is obtained by sighting collimator targets erected on special pads at each top corner of the gearcase from a datum plane located above the secondary reduction gearwheel after bearing.

Each shipset of gearing is tested up to full power using the power circulation of "back-to-back" method of loading (Figure 7). A hydraulic vane-type torque applier is coupled between the forward ends of the two second reduction gearwheels which are provided with forward coupling flanges especially for that purpose. The required power to rotate the gearing is provided by two 600 h.p. variable speed motors driving through flexible couplings fitted to the after ends of the main quill shafts in one gearbox. This method of testing permits the gearing units to be loaded independently of the speed but requires one unit to act as a speed increaser, that is with the astern flanks being loaded under ahead rotation. It is therefore necessary for all trials to be repeated with the loading reversed in order that each unit may be tested under the rated power conditions.

The gearing is slowly run up to full power speed with the minimum torque necessary to prevent chatter being applied and using extreme pressure oil. The torque is then increased in stages until full power is attained after a total running period of up to twenty hours. The gearing is run at full power for four hours and then subjected to a further eight hours testing with propeller law loading up to full power. The gear units are finally subjected to a fifteen minute full power trial with 130 per cent torque and a proportionate reduction in speed. The total shop testing time is approximately 60 hours per shipset of gearing.

Shop testing was initially carried out with both the three and five point supports. The results of these tests confirmed the earlier experience at Pametrada, that the gearing is capable of satisfactory operation with either type of support, in spite of the amount of twisting produced with the after corners of the gearcase unsupported. In consequence it has become the approved practice to install the gearing on the test bed and in the ship on a three-point support and then to fit the remaining torque resisting chocks.

Service Experience

Service experience with the main gearing in all fourteen ships of the *St. Laurent* Class, over the last five years since commissioning has been excellent. The appearance of the gear teeth differs from the original condition only by a slight polishing of the original grinding patterns.

One of the ships, with the revised gear design, has now been running for almost a year with standard turbine oil after satisfactorily completing a four hour full power trial to prove the capability of the gear design. It may be noted that the ability of a gearing design to permit operation with a standard turbine oil, continues to be a recognized naval requirement, regardless of whether extreme pressure oils are used in service.

Main gearing tooth mating patterns observed both on the test bed and particularly in ship installations have not always compared with those obtained on the meshing frame. Low power tooth contacts have been observed at the driving ends of the pinions. While the satisfactory condition of the gearing obviated the need for concern, efforts were

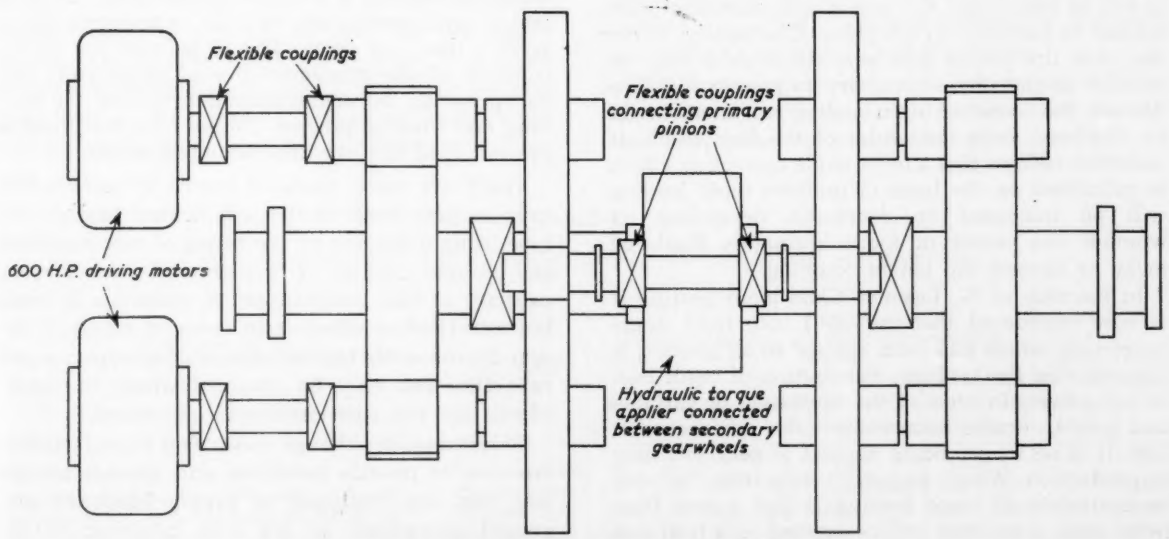

Flexible couplings
Flexible couplings connecting primary pinions
600 H.P. driving motors
Hydraulic torque applier connected between secondary gearwheels

Figure 7. Arrangement of power circulation rig.

made to diagnose the cause of what might have been mistakes for gearcase misalignment.

The most obvious factor emerging from this investigation was the effect of propeller shaft alignment on the meshing of the secondary reduction gearwheel. Due to the lightness of the main gearwheel and the absence of a separate thrust shaft, it was found to be most important for the main gearing to be aligned in the ship installation so that the intermediate propeller shaft would not exert a bending moment on the gearwheel and cause it to lift at the forward end. Main gearwheel lifting at low powers affects not only the mating patterns in the secondary reduction but also the load distribution between its mating pinions where they are in a locked train. Again, this effect has not been found to be deleterious to the gear teeth, but in conjunction with other factors can lead to gearcase knocking due to tooth separation at low powers.

A precise analysis of all the conditions affecting tooth mating patterns in single helical gearing—such as journal attitudes in clearance bearings, hydrodynamic influence of the oil film, quill shaft restraint and gearcase torsional and thermal distortion—can best be described as being virtually impossible. The conditions can, however, be analyzed, sufficiently to indicate that the conventional basis for determining helix angle correction, in consideration of torsional and bending deflections, is entirely inadequate for single helical gearing. The slewing effect resulting from the axial thrust component of single helical tooth loads, causes different angular attitudes of the pinion and gearwheel journals between forward and after bearings. The pinion and gearwheel axes are therefore not parallel to their respective bearing axes. If the maximum tooth loading is assumed to be equally distributed along the face width, as for double helical gearing, then it will be found that the pinion and gearwheel axes cannot be parallel to each other. Conversely, in order that the pinion and gearwheel axes may be parallel in the plane necessary to permit full face contact, the center of tooth loading must necessarily be displaced from the center of the face width. It therefore follows that a helix angle correction which is calculated on the basis of uniform tooth loading will be increased or decreased depending on whether the center of tooth loading is displaced away or toward the pinion coupling.

In the case of *St. Laurent* Class main gearing it is now considered that the .0004 inch helix angle correction, which had been applied to all pinions, is not ensuring the uniform distribution of tooth load at full power. In view of the multitude of variable and indeterminates concerning helix angle correction, it is no longer being applied to gear sets now in production. Where prototype shop trials indicate concentration of tooth loading at full power then helix angle correction will be applied on a trial and error basis.

It may be concluded that the high margin of safety obtainable with hardened and ground gearing has been well demonstrated by their trouble-free service in *St. Laurent* Class where it has been subjected to unknown concentrations of tooth load due to the doubtful application of helix angle correction and the effects of considerable gearcase twisting. It is considered most unlikely that soft gearing, which is believed to be particularly sensitive to malalignment, would be able to withstand these same conditions of operation.

THE MERCANTILE APPLICATION FOR HARDENED AND GROUND GEARING

Although several tankers and at least one ocean liner are now fitted with hardened and ground gearing and have given completely trouble-free service over a period of several years, the general use of this type of gearing in merchant ships is still not widely recognized. Of the many requirements which would conceivably influence the choice of hardened and ground gearing, the need for improved reliability would, it is thought, be high on the list in view of the incidence of gear tooth failures, ranging from premature wear to pitting and breakages, which continue to be reported in soft or hobbed and shaved type gearing. It is apparent that the highest proportion of mercantile main gearing failures are in aft end machinery installations.

The reduction of weight and space obtained with hardened and ground gearing is unlikely to be an important asset in tankers and may in certain cases even create some difficulty in permitting adequate condenser space. It is considered that the condenser problem would only be acute in a two turbine dual tandem articulated gearing arrangement where the height between the turbine and propeller shaft centers would be a minimum. In spite of its higher load carrying capacity it does not appear that hardened and ground gearing can be built to transmit higher powers than soft gears. This is because the torque capacity of the maximum size of gearwheels that can presently be manufactured by either the hobbing and shaving process (200 in.) or the grinding process (142 in.) are approximately equal.

There are many cases on record of surface failures in gear teeth of the soft hobbed and shaved type being overcome by the fitting of case-hardened and ground pinions. The increased load-carrying capacity of this combination of materials is small but nevertheless effective in cases of marginal design. Significantly higher load-carrying capacity and reliability can only be obtained where the gearwheels are also case-hardened and ground.

Unfortunately although many gear manufacturers are able to provide hardened and ground pinions very few are equipped to supply hardened and ground gearwheels or are even prepared to acknowledge the advantages of this type of gearing.

While there can be little doubt that the outlook of the gearing industry on this matter is influenced to no small degree by existing machine tool investments, it is curious to note that hardened and ground gearing is commonly condemned on the basis of slow and costly manufacture. The suggestion of the manufacturing time for marine hardened and ground gearing being excessive has most certainly not been borne out by experience in Canada. Furthermore, in consideration of the tremendous strides which have been made in improved gear hardening methods, particularly the tooth-by-tooth induction hardening process [4] which can be applied to medium and large gearwheels, there can be little doubt that hardened and ground marine gearing is beginning to look economically attractive.

The removal of hardened gear material by grinding is unquestionably a much slower process than the removal of soft gear material by hobbing and shaving. However, in consideration of the reduced gearwheel diameters and face width permitted by utilizing the high load-carrying capacity of case-hardened gearing, the overall manufacturing time required to process the smaller gear tooth area would appear to be less than for the larger hobbed gears. In point of fact it is known that a much higher proportion of the total manufacturing time for a set of main gearing is spent on the gearcase and assembly than on the manufacture of the pinions and gearwheels. It might then be stated that the cost of a set of gearing is influenced far more by the size of the secondary reduction gearwheel than the gearcutting times.

To obtain an approximate estimate of the order of cost saving, which might be achieved by using case-hardened and ground gearing, a comparison of gear sizes has been made in Table V for the same torque requirement applying the Lloyd's K factors recommended by Page [2] for merchant ship applications. The figures listed are relative to a basic design employing K factors of 80 and 70 in the primary and secondary reductions respectively. Gear manufacturing times per unit peripheral area have been estimated on the basis of comparisons which have been made with respect to the carburized and hardened grinding times reported in Table V. The relative cost indices for complete main gearing units have been derived in consideration of the size of the secondary reduction gearwheels, the peripheral (toothed) areas and the manufacturing time indices.

CONCLUSIONS

The high reliability provided by hardened and ground gearing and its ability to withstand concentrated tooth loads, due to various internal and external factors causing misalignment, without distress has been demonstrated by the experience with *St. Laurent* Class in the Royal Canadian Navy. A high pressure angle is recommended to avoid scuffing but this should not exceed 20 deg in the interest of ease of manufacture.

The overall manufacturing time required to produce a set of hardened and ground gearing may be expected to be appreciably less than for an equivalent soft gear design for the same power/speed requirement. Experience with induction hardened gearwheels running with carburized and hardened pinions is still very limited but, from the indications of tests so far conducted, it is considered that this type of gearing will become equally attractive for naval and mercantile installations alike on the basis of reliability and cost.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance given by the Resident Naval Overseer, Lachine and his staff in compiling manufacturing data and to thank the following companies and bodies for the use of illustrative material: Department of Mines and Technical Services, Ottawa, Dominion Engineering Works Ltd., Montreal, Pametrada, Wallsend and Maag Gear Wheel Co. Ltd., Zurich.

This paper is published with the permission of the Royal Canadian Navy but the responsibility for any views expressed rests with the author.

TABLE V

Relative Dimensional and Cost Indices for Hardened and Soft Gearing

Gear material		Gear type	Primary reduction				Secondary reduction				Manufacturing time index per unit toothed area	Cost index
Pinion	Gearwheel		K factor	Diameter	Face width	Unit tooth load	K factor	Diameter	Face width	Unit tooth load		
Soft (basis)	Soft (basis)	Double helical	80	1	1	1	70	1	1	1	1	1
Through hardened	Through hardened	Double helical	120	0.87	0.87	1.31	100	0.89	0.89	1.27	1.5	0.96
Carburized and hardened	Induction hardened	Single helical	250	0.77	0.54	2.41	250	0.78	0.47	2.78	1.5	0.73
Carburized and hardened	Carburized and hardened	Single helical	300	0.73	0.51	2.72	300	0.73	0.44	3.14	2.5	0.76

REFERENCES

[1] Newman, A. D. 1958. "Load Carrying Tests of Admiralty Gearing," International Conference on Gearing.
[2] Page, H. H. 1958. "Advance in Loading of Main Propulsion Gears," International Conference on Gearing.
[3] Chesters, W. T. 1958. "Study of the Surface Fatigue Behavior of Gear Materials with Specimens of Simple Form," International Conference on Gearing.
[4] Chamberlain, A. 1958. "Developments in the Heat Treatment of Large (Marine) Gears," International Conference on Gearing.
[5] Braddyll, J. R. G., and Oldham, M. C. 1959. "High Torque Merchant Ship Gearing." Trans.N.E.C.I.

AIRCRAFT JET FOR MARINE USE

The Model 240 turboshaft engine, a modified version of General Electric's J79 turbojet engine which currently powers four types of military Mach-2 aircraft, will be installed in the Maritime Administration's experimental hydrofoil craft this summer. Foils attached to the sides of these craft cause the hull to lift out of the water, reducing the displacement resistance ("Mechanical Engineering," June, 1959, pp. 48-53).

Various configurations of the turboshaft engine and exhaust system are also planned for use in mobile electric-power systems for remote or emergency uses, and as prime movers for peaking power generators. The unit's lightweight, high-power characteristics make it ideally suited for such selected industrial and electrical applications.

This new marine engine consists of the basic gas generator used in the J79 turbojet, plus an aftmounted power turbine that converts high-velocity jet exhaust into shaft horsepower. As a comparison, in a jet plane, jet-engine exhaust causes a reactive thrust that powers the aircraft. In the hydrofoil craft, a windmill-like turbine harnesses jet exhaust to drive the craft's screw propeller. The Model 240 engine will power the Maritime Administration hydrofoil at speeds up to 60 knots.

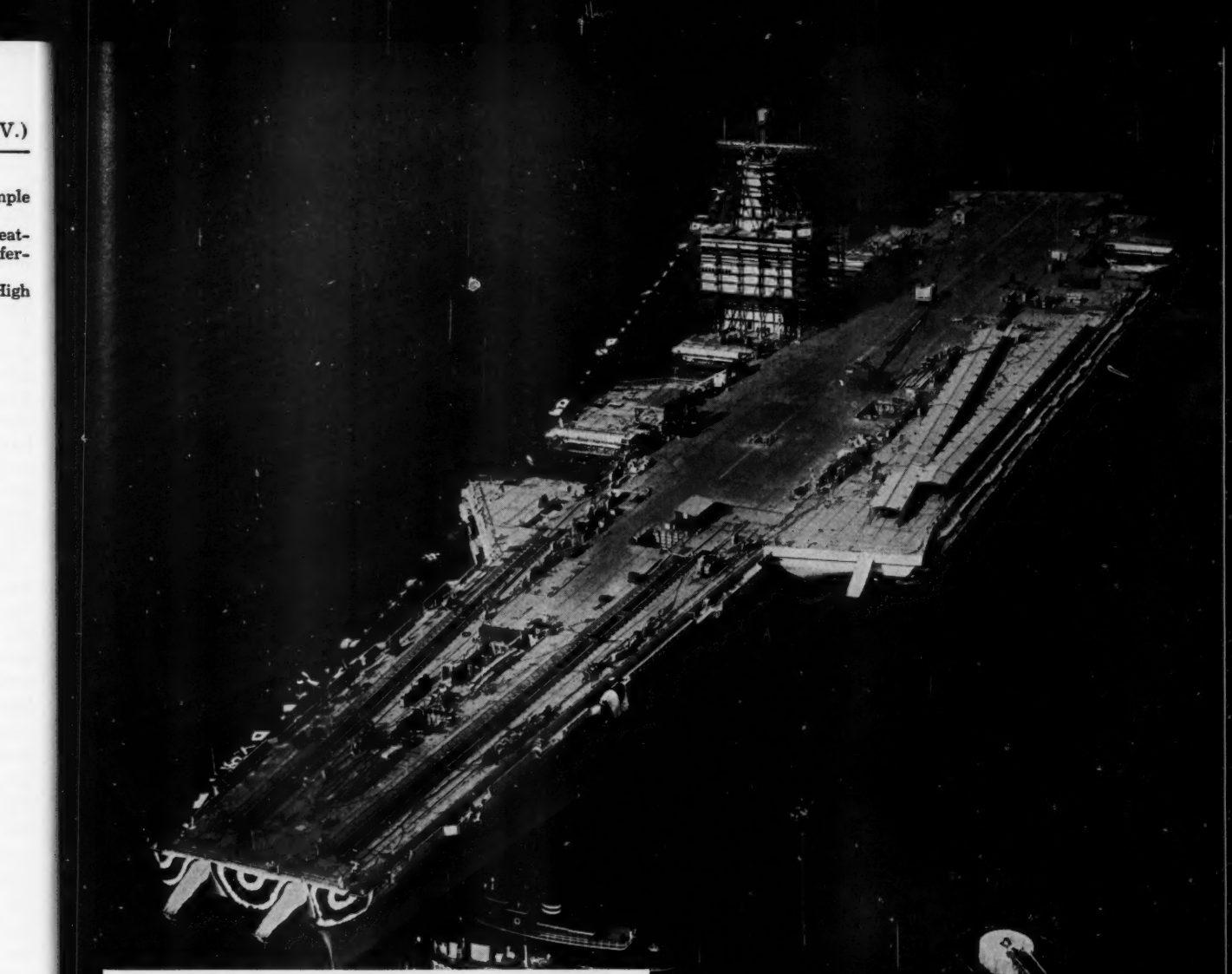
The 104-ft craft is being built by Dynamic Developments, Inc., an affiliate of the Grumman Aircraft Corporation.

Though General Electric has produced marine propulsion systems for more than 50 years, the J79 turbo-jet is the first large jet engine to be converted to sea-duty. Like the J79, the Model 240 turboshaft engine has a very favorable power-to-weight ratio, fulfilling hydrofoil craft requirements for a lightweight, compact, high-performance power plant.

The J79, America's first Mach-2 turbojet, delivers more thrust per pound of engine weight than any other turbojet in its class.

Later versions of the Model 240 turboshaft engine will use the gas generator from the Company's CJ-805 turbojet in place of the J79 gas generator. The CJ-805 engine is the commercial version of the J79 turbojet. It is now in regular airline service powering the Convair 880 jetliner.

Mechanical Engineering, June 1961



giant guardian...

Four football fields could be laid out on the flight deck of the giant, nuclear-powered U.S.S. Enterprise—the world's largest ship. But size isn't the only dimension that makes the Enterprise outstanding. Pressurized water nuclear reactors, producing over 200,000 horsepower, will drive her at speeds in excess of 25 knots. She will be able to sail the seven seas for several years without refueling.

Carlson corrosion and heat-resistant stainless steel plate was used in this huge Attack Aircraft Carrier, and in her nuclear power plant. The builders of the Enterprise have confidence in the stainless plate produced by Carlson specialists. Exacting quality standards and dependable delivery result from such specialization.

Whether you are building a gigantic ship, a nuclear power plant, or corrosion-resistant process equipment, we can help you make it best. For practical assistance in filling your requirements for stainless plate in a wide range of grades and sizes, contact Carlson.

Our new booklet, "Producing Stainless Steels . . . Exclusively," is available. Write for your copy now.

Photograph of the launching of the U.S.S. Enterprise. Courtesy of Newport News Shipbuilding & Dry Dock Co.

OFFICIAL U.S. NAVAL PHOTOGRAPH

G.O.CARLSON Inc.

Producers of Stainless Steel

160 Marshallton Road
THORNDALE, PENNSYLVANIA
District Sales Offices in Principal Cities

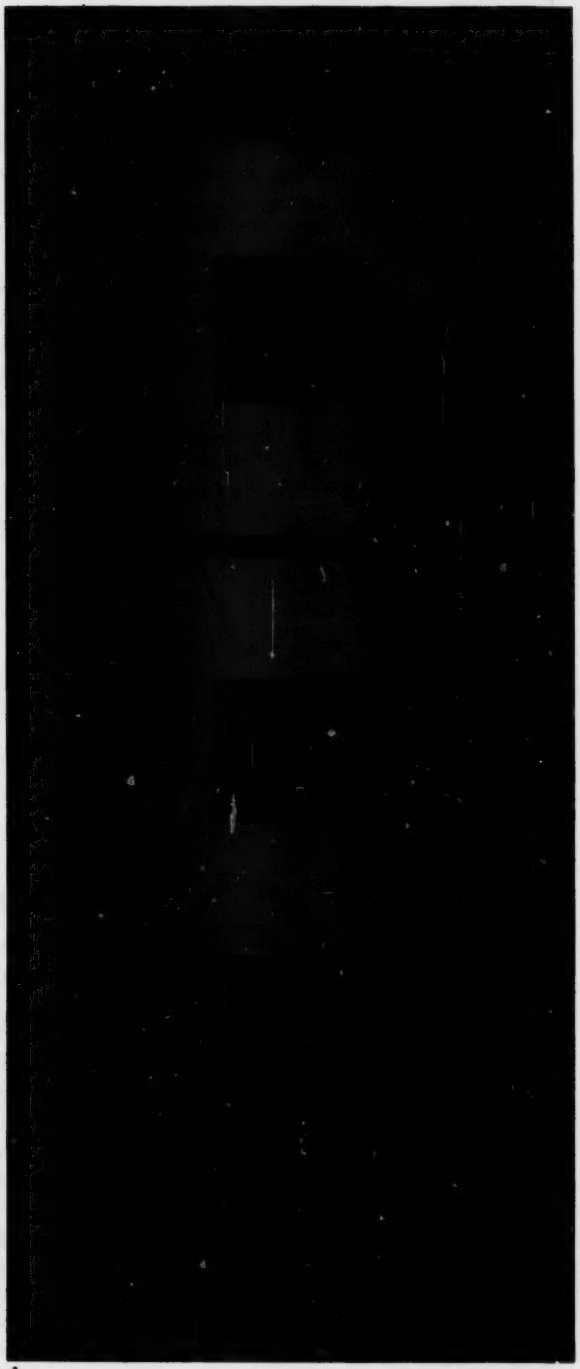
Plates • Plate Products • Heads • Rings • Circles • Flanges • Forgings • Bars and Sheets (No. 1 Finish)

a.

b.

Westinghouse invites you to test your weather I.Q.

c.



d.

Your weather eye rates 100% on this mariner's test if you named: a. small craft warning (winds up to 33 knots). b. gale warning (winds ranging from 34 to 48 knots). c. whole gale warning (winds ranging from 48 to 63 knots). d. hurricane warning (winds 64 knots and above). ■ But no matter what the weather, your ships sail safely, surely, soundly, with proven Westinghouse propulsion and auxiliary equipment aboard. ■ Large or small, from turbines to Trinistors,® Westinghouse can supply more shipboard equipment than any other manufacturer. ■ Contact your local Westinghouse sales engineer for product information. Or write us: Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pennsylvania. You can be sure . . . if it's **Westinghouse.** J-92057

DON'T HONK—Celebrating its 57th Anniversary, June 16, U.S. Naval Engineering Experiment Station, Annapolis, unveiled a "magnetically clean" lab with precision instrumentation and equipment so sensitive that it can measure accurately the magnetic field of an automobile passing more than 300 feet away. Non-destructive electronic test gear and magnetic field measuring devices—a $200,000 investment—were installed in the facility by Magnaflux Corp., subsidiary of General Mills. Location and identification of major magnetic field sources within various types of shipboard electrical equipment is one of the important assignments of the lab. It is built on heavy concrete reinforced with aluminum rod; has walls of cinder block, aluminum mesh—reinforced, roof of composition material laid across wooden beams, and aluminum nails throughout. Relative permeability of the installation is reported less than 1.02 within 288 feet.

Research/Development Magazine, August 1961

ARTIFICIAL ELECTRICAL NOSE

Long-range, fundaental work has been undertaken by ARF research personnel to understand, match, and eventually surpass the mechanism of olfactory sense. They are currently attempting to establish which groups of physiochemical surface interactions can exhibit selective electrical effects suitable for recognizing low concentrations of certain vapors in the air. Eventually, an "artificial electrical nose" ma ybe developed, which would objectify the detection and analysis of odors. ARF researchers presently use a variable capacitance capacitator to compare contact-potential changes caused by the same vapor on several solids.

The eventual benefits from an artificial olfactory detector are enormous. Experienced doctors, for example, can recognize many sicknesses by the smell of the skin or body products. Large areas of diagnostics may thus be opened by objective olfactometry. Warning systems for toxic vapors in the air could be devised for industrial safety and for protection of military personnel. Olfactory examinations could also be made at a distance, as in space or other remote regions. Food aroma studies could be put on an objective basis, and methods of detecting food spoilage without extended tests might be developed.

Although the mechanism of olfactory sense is not yet fully understood, adsorption appears to be one link in the complex physiological process. ARF researchers theorize that adsorbent surfaces must exist that are highly selective with respect to molecular structures of adsorbed species. Since the final link in olfactory reception is an electrical impulse to the nervous system, it is probable that selective adsorption is signaled as a change in the potential of the interface.

Armour Research Foundation "Frontier"

IRVING GRANET and WILLIAM J. GUMAN

EXPERIMENTAL PROGRAM FOR A PLASMA PINCH SPACE ENGINE

THE AUTHORS

Irving Granet received his B.M.E. from The Cooper Union; his M.M.E. from Polytechnic Institute of Brooklyn; has taken Pre-Doctoral Studies at Polytechnic Institute of Brooklyn; and is a graduate of the Oak Ridge School of Reactor Technology.

He has worked in Republic's Plasma Propulsion Laboratory on nuclear propulsion systems, space radiators, thermodynamic power cycle considerations for generating electric power, and system design and operation for space propulsion. He was formerly Director of Staff Engineering, Nuclear Energy Department, of Foster Wheeler Corporation where he directed engineering design and analysis for complete nuclear plants. Mr. Granet has taught thermodynamics and heat transfer at the Polytechnic Institute of Brooklyn, and at present is Adjunct Assistant Professor of Engineering and Physics at Long Island University.

He has published over 40 articles in the fields of thermodynamics, applied mechanics, heat transfer and nuclear energy. He is a member of the American Society of Mechanical Engineers, National Society of Professional Engineers, Pi Tau Sigma and Sigma Xi. He is a licensed Professional Engineer in the State of New York. Mr. Granet is listed in the 1960 edition of American Men of Science and is a reviewer for the American Chemical Society's technical publications.

William J. Guman received degrees of B. Aero. E., M. Aero E., from and has completed courses for Ph.D. Aero. E. at Rensselaer Polytechnic Institute. Since coming to Republic in 1959, Mr. Guman has been conducting theoretical and experimental studies on non-steady interactions and flow processes in plasma engine configurations. Mr. Guman was Assistant Professor at Rensselaer Polytechnic Institute lecturing on fluid mechanics, aerodynamics, performance and stability, and conducting laboratory courses in experimental fluid dynamics and wind tunnel research. He also investigated flow induction and was head of Rensselaer's supersonic wind tunnel laboratory.

Mr. Guman performed a theoretical analysis in experimental aerodynamics at Avco, and conducted analyses of experimental flight test data at Grumman.

Mr. Guman has authored papers published in the Journal of the Institute of The Aeronautical Sciences, Journal of Applied Physics, Journal of the American Rocket Society and the Physics of Fluids. Mr. Guman is listed in the 1960 edition of American Men of Science and is a member of the Institute of the Aeronautical Sciences, Tau Beta Pi, Gamma Alpha Rho and Sigma Xi.

INTRODUCTION

In a recent paper [1] the use of the electromagnetic pinch effect for space propulsion has been described in some detail. Theoretical studies using four analytical models were reported and certain significant conclusions were made based upon these studies. At the time that this earlier paper was written, experiments had been conducted and "proof of principle" had been established. Since that time, an extensive experimental program has been conducted at Republic's Plasma Propulsion Laboratory and is reported in this paper. The field of plasma diagnostics is a very difficult one due to the fact that it requires the ability to measure events occurring in less than one millionth of a second in the presence of large magnetic and electric fields. Since the process proceeds with velocities of the order of 100,000 miles per hour or greater, reliable measurements become very difficult to obtain.

Prior to discussing the experimental program it is briefly in order to answer two pertinent questions, namely, "why have space missions?" and "where is each of the proposed propulsion systems applicable?" Table I [2] gives a partial listing of the many space missions that are desirable. As a last item, national prestige has been listed. Of all the reasons for space flight, this one should not be minimized. It is necessary in the political atmosphere that exists at present in the world that the United States should demonstrate spectacular space accomplishments. The balance of political power could easily rest on some spectacular, non-technical space shot.

In order to answer the second question of applicability of each of the proposed space propulsion systems it is necessary to make certain broad estimates. Figure 1, taken from many sources in the literature, gives the general range of performance and applicability of the most feasible propulsion systems. The ordinate is acceleration in "g's" and represents the ratio of thrust to weight. Therefore, those systems whose "g" value is less than unity

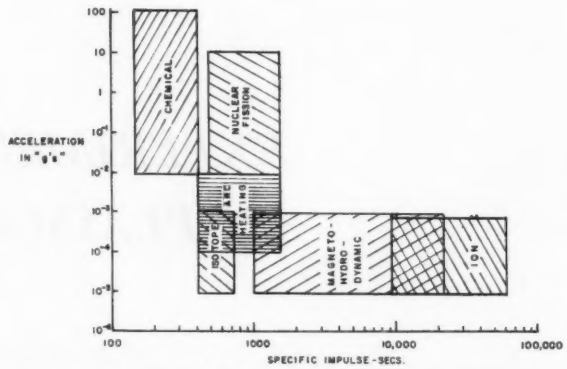


Figure 1. Acceleration and Specific Impulse Spectrum.

cannot take off under their own power from earth. Only the chemical and nuclear fission devices can. The other coordinate, specific impulse is the ratio of velocity to "g" and represents the ratio of thrust developed to weight flow rate. Except for the magnetohydrodynamic and ion engines, this figure shows that the maximum specific impulse is of the order of 1500 secs. This limitation is primarily due to materials limitations. The ion engine has difficulties at specific impulse less than 10,000 secs. arising from its extremely low efficiency in this range and there appears to be a major problem area due to electrostatic space charge phenomena.

The magnetohydrodynamic devices have a useful range of specific impulse ranging from 1,000 to 20,000 secs. System and mission studies performed at Republic [3] have indicated that for presently conceived earth-orbit missions and for an earth-orbit to Mars-orbit mission the optimum specific impulse is in the range of from 1,000 to 7,000 secs. It should be noted that the magnetohydrodynamic devices fall into two categories, pulsed and steady flow.

As was indicated in [1], the pulsed device shows certain advantages such as low average material temperatures, small loss of electrode material over extended operational periods, reliable start-stop operation, etc.

TABLE I

TYPES OF FUNCTIONAL MISSIONS

I. *Space Environment Missions*
- A. Physics
  - 1. Atmospheric
    - a. Composition
    - b. Total density
    - c. Electron and ion density
    - d. Air glow or auroral
  - 2. Magnetic fields
  - 3. Micrometeorites
  - 4. Cosmic radiations
    - a. Composition, direction, and energy
    - b. Primary electrons and protons
    - c. Primary gamma (x-rays)
    - d. Ultraviolet and infra-red
    - e. Light, color, and intensity
    - f. Galactic noise, below ionospheric cutoff
- B. Space environment
  - 1. Exposure of:
    - a. Materials
    - b. Equipment
    - c. Living things (recovery is necessary)
      Bacteria and yeast organisms
      Flowering plants
      Rats
      Monkeys
      Man

II. *Astronomical and Astrophysical Missions*
- A. Low-resolution optical scanning in ultraviolet and infra-red of the sun, moon, planets, and galaxy (stars, clouds, space).
- B. High-resolution optical survey in far ultraviolet of the sky
- C. Solar radiation
- D. Radio astronomy, below ionospheric cutoff of solar, planetary, galactic (stars) noise.

III. *Meterological Missions*
- A. Cloud cover plus atmospheric heat balance
- B. Atmospheric heat balance only

IV. *Communication Missions*
- A. Propagation and ionospheric measurements
  - 1. Electron density
  - 2. Electron density above F-layer
  - 3. Magneto-ionic ducts
  - 4. Propagation
- B. Satellite communication
- C. Worldwide communcation relays
  - 1. Active
  - 2. Passive (nonspherical)

V. *Technological Missions*
- A. Precision orbital measurement for
  - 1. Geodetic
  - 2. Relativistic effects on orbits, atomic clock
  - 3. Improvement of tracking and launch-guidance systems
  - 4. Orbit modifications and transfer
- B. Power Systems
  - 1. Solar power collectors (parabolic)
  - 2. Cooling radiators
  - 3. Energetic liquids stored at low temperature and shielded from sun
- C. Stabilization systems for
  - 1. Small payloads
  - 2. Medium payloads
  - 3. Large payloads
- D. Guidance systems
- E. Space flight propulsion
- F. Reentry and recovery
- G. Manned Satellite

VI. *Transport and Supply Missions*

VII. *Military Missions*
- A. Early warning
- B. Weapon delivery

VIII. *National Prestige*

EXPERIMENTAL PROGRAM

GENERAL

In order to properly supplement the theoretical areas of investigation, Republic's Plasma Propulsion Laboratory has designed, constructed and tested several test units specifically built and instrumented for research in the field of plasma physics. As an adjunct to this experimental program, Republic has accumulated considerable experience in the selection and design of such equipment as switches (triggered gap switches, solenoid operated vacuum switches, ignitrons, thyratrons); capacitors; vacuum pumping and measuring equipment; high power transmission (coaxial cables, connectors, strip lines); insulation (ceramics, plastics); and inductance coils.

Experimental investigations in this field are difficult and require carefully planned and executed diagnostic programs. Republic's experience from both the theoretical and practical viewpoints is extensive and detailed. The Plasma Propulsion Laboratory has developed and utilized advanced concepts of streak photography, ionization probes, light probes, magnetic probes, pressure transducers, etc. In addition, a considerable amount of experience has been gained in the placing of instrumentation to reduce its detrimental influence on the behavior of the plasma.

Some of the principal test units that have been used for these programs are:

Test Rig No. 1.
Test Rig No. 2
Triggered Gap Switch.
Fast Acting Gas Valve.

A brief description of these units in which their use and capability are indicated follows.

TEST RIG No. 1

Test Rig No. 1 has been used as a system for general experimentation with plasmas. Figure 2 is a photograph of Test Rig No. 1. It is on this rig that pinch experiments have been made using gas triggering and electrode nozzles to demonstrate the feasibility of a pulsed plasma pinch space engine. Considerable experience has been obtained on this rig with gas triggered discharges, and knowledge has been acquired on the requirements for obtaining this type of discharge between electrode nozzles of various shapes. In the course of this work, interesting data pertinent to a propulsion system have been obtained.

One of the most important considerations for an electric propulsion system is the initiation process, i.e., the processes affecting the establishment of a pinch, its stability and its strength. In order to investigate this fundamental parameter, it was necessary to determine and develop certain circuit requirements. To this end the current rise time and the ringing frequency of this rig have been altered by the insertion into the electrical circuit of coils of various values of inductance and resistance. These coils have been made at Republic and are used to vary the rate at which a pinch is propagated into the gas located in the inter-electrode spacing. The coils have been used particularly in stability studies of the action of a "slow" pinch and this work has been reported by T. Donner and L. Aronowitz [4].

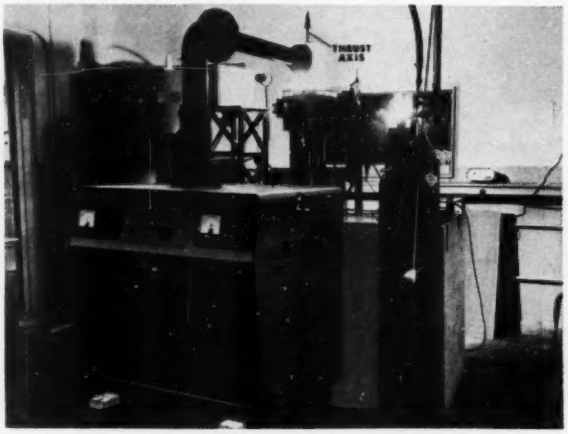


Figure 2. Test Rig No. 1 During Operation

A streak camera has been used with this rig as have other forms of instrumentation, such as light probes for velocity measurement, pressure transducers (Kistler gauge and barium titanate pellets) and current sensing coils in a plasma stream. Important knowledge has been obtained of the effect of instrumentation on discharges and pinches and of the influence of temperature, pressure, magnetic fields and voltage on instrumentation. Valuable experience has been acquired on the interpretation of instrumentation results and on the general techniques applicable to experimentation in this field.

TEST RIG NO. 2

Test Rig No. 2, designed for use in investigating the production and acceleration of plasmas for space propulsion applications, has been operating successfully for some time and valuable data have been obtained. The greater flexibility built into this test rig has been a major factor in obtaining extensive experimental data pertinent to the design of a space propulsion system. Figure 3 is a photograph of the unit showing all of the principal components and some of the instrumentation.

The components of Rig No. 2 are described in some detail in the following discussion:

Electrode Nozzles: Experience with aluminum

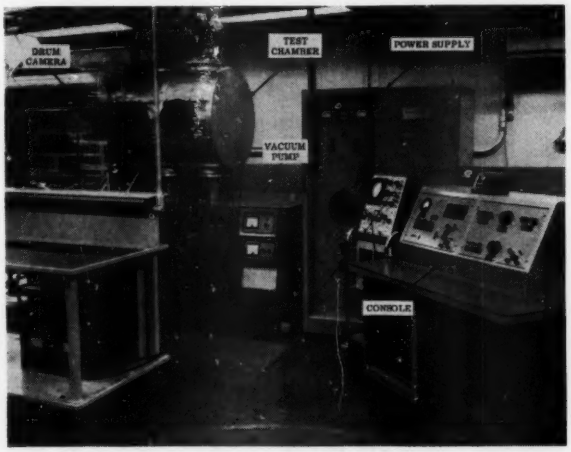


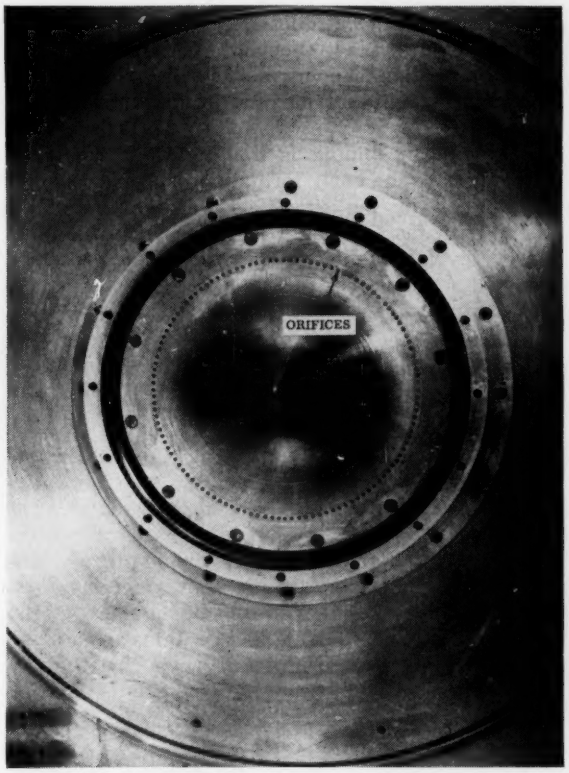
Figure 3. Test Rig No. 2.

electrode nozzles has shown that they have very little erosion over long periods of operation and, furthermore, that the operational temperature of the nozzles stays less than 220°F. In these nozzles, the pinch is initiated by the introduction of the propellant through a series of holes or slots near the outer periphery. Figure 4, a typical nozzle, has the top electrode removed and shows the propellant supply orifices.

The upper and lower electrodes are separated at the outer periphery by an electrical insulator. Enflon has been used successfully, and at no time was it found that arc-over from one of the electrodes to the other occurred due to the accumulation of debris at the surface of the insulator. Numerous electrode shapes have been tried, and the experimental results obtained on radially dominant, quarter circle and elliptic nozzles are presented in another section of this paper.

Capacitors: The pinch discharge depends upon low source impedance of a bank of capacitors for proper performance. It has been empirically determined that at this experimental state of the art, reliable pinching can be achieved at approximately 120 microfarads and 3000 volts. The present experimental rig uses industrial type capacitors that weigh two pounds per microfarad. Each of the capacitors used is 30 microfarads and is capable of being charged to 6000 volts. A study program has been initiated at Republic with several prominent capacitor manufacturers to obtain small, light, reliable high-energy capacitors. This is a continuing program and some benefits have already been derived and are incorporated in Prototype Test Engine No. 3, which is described later in this paper.

Vacuum Chamber and Vacuum Pumping Subsystem: The vacuum chamber is 30 inches in diameter by 36 inches long, and is of welded aluminum construction. This chamber is presently operating



Fiure 4. Typical Nozzle Showing Propellant Supply Orifices.

at vacua of 10^{-4} mm Hg and has a capability of even lower pressures. Ultimates of 5×10^{-7} mm Hg have been achieved with the pumping system using water cooled baffles. The system is composed of six inch diffusion pumps, water cooled baffles, a mechanical backing pump and a mechanical holding pump. In its present mode of operation, gas is injected into the chamber in pulses; each pulse being of the order of 5×10^{-3} gms mass. The unit is capable of maintaining a vacuum of 10^{-3} mm when it is pulsed at the rate of one pulse per second, demonstrating its capability to "clean up" this throughput.

Port holes are provided for visual inspection and streak photography. Connectors to plug-in instrumentation and monitoring equipment are provided as shown in Figure 3.

Electrical Subsystem: The test rig is operated by discharging a bank of capacitors across a shaped electrode assembly. The capacitors are stored in the cylindrical rack which is capable of acommodating 20 units rated at a total capacity of 600 microfarads at 6000 volts. These units can be subjected to a dead short repeatedly without damage. The capacitors are connected to a central collection drum by low resistance, low inductance coaxial cables to provide ease of arrangement, access and maintenance of the collectors. The entire circuit has an inductance of 0.030 microhenrys, including capacitors, cables, col-

lector drum and electrodes. The system has a ringing frequency of 50 kilocycles per second under normal operation, showing a rise time of five microseconds to maximum current in the first quarter cycle.

A significant finding is that a fast current rise contributes to the early formation of a good current sheath, one of the essentials to obtain a stable pinch. With fast current rise (even with minimum energy levels), stable pinches have been obtained without external pre-ionization, other than normal background radiation.

Several power supplies are available that can charge the capacitors in times ranging from less than one second to several seconds.

Control Console: The console shown in Figure 3 contains the controls for the general operation and monitoring of the engine system. Automatic sequencing circuits are provided such as that for the operation of a streak camera. In this circuit, after the initial parameters of the experiment are established, the operation of the streak camera is automatically keyed in to make each exposure at the correct time. The console also contains a panel to control the operation of the gas valve. The frequency as well as the duration of the gas pulse can be controlled from the console.

Triggered Gap Switch

An experimental assembly utilizing the inverse pinch process was devised as an application of the inverse pinch to develop a triggered gap switch. Republic is interested in the use of such a high-energy switch for application in pulsed plasma devices in order to take advantage of the self-extinguishing feature of such a geometry. The equipment is also being used for general investigation into the physics of an inverse pinch, particularly in its application as a high current density switch. The unique feature of this device is that it can be used both as a switch and a valve for controlling propellant injection. Figures 5 and 6 show the triggered gap switch developed at the Plasma Propulsion Laboratory at Republic.

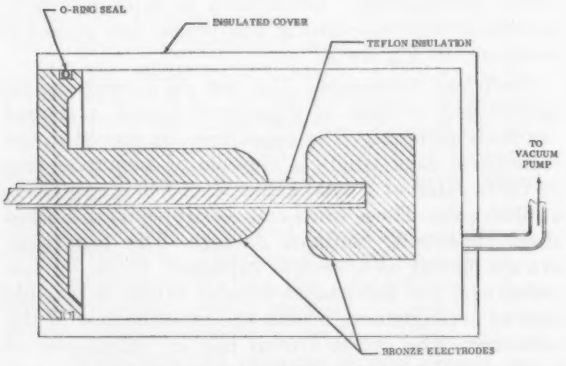


Figure 5. Triggered Gap Switch Schematic.

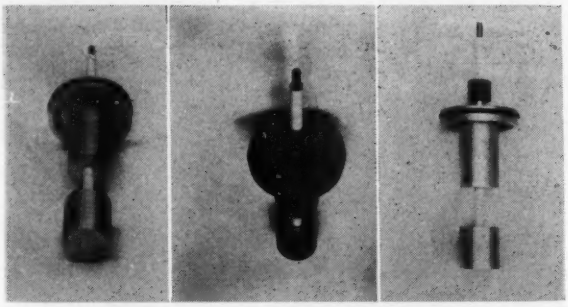


Figure 6. Views of Triggered Gap Switch

Fast Acting Gas Valve

During the early investigations, it was realized that gas triggering of high energy discharges was advantageous. Such a mode of operation eliminates the need for a triggered gap switch in a propulsion system. This form of initiation has now become standard at Republic and is utilized in all propulsion experiments. Although commercial valves can be used for this purpose, it is readily apparent that some applications require better gas utilization and propellant injection control than is available with commercial equipment. In an attempt to meet some of these requirements, Republic has been developing a valve of unusual design. Several valves and their assorted electrical circuits have been made and are currently being evaluated.

DIAGNOSTICS

The ultimate purpose of an engine for space propulsion is to provide thrust for the specified mission efficiently so that the total weight of the propulsion system is minimized. In order to properly design a device to meet this objective, it is necessary to be knowledgeable in all subsystem areas pertinent to the engine. In this section the parameters of particular interest for engine development are categorized. Diagnostic equipment and pertinent specific test data will be presented. The areas of interest and also those in which the Plasma Propulsion Laboratory has expanded a great deal of experimental effort are:

Velocity of the plasma in the engine and the velocity of efflux of the plasma from the engine.

Mass of propellant injected per pinch and the mass of propellant actually involved in the electro-gas dynamical processes after initiation of the pinch.

Thrust of the device.

Electrodynamic parameters of the system.

Pinch initiation requirements.

It must be emphasized that the electro-gas dynamical transients associated with such an engine require diagnostic ability to obtain reliable data in times of the order of one microsecond or less in the presence of extremely large transient magnetic

fields. Therefore, in each of the foregoing areas, several techniques have been used to obtain reliable, reproducible data. In the following material some of the pieces of special test equipment in use at the Plasma Propulsion Laboratory are briefly described prior to the presentation of specific experimental results.

Rotating Drum Camera

Republic (in conjunction with Photo Mechanisms,, Inc.) designed and built a high speed rotating drum camera. This camera monitors the movement of a plasma over a length of 12 inches from a distance of 20 inches. When the film is projected to full scale, the time resolution is four microseconds per inch. Ten microsecond timing markers and a zero time mark are placed on the film simultaneously with the exposure of each event. Figure 7 shows this camera as used in Test Rig No. 1.

Rotating Mirror Camera

A rotating mirror camera has recently been purchased. Continuous optical records of the plasma motion can be obtained by means of hexagonal mirror rotating up to 3000 rps. At the peak speed, the mirror provides a writing speed of 3.9 millimeters per microsecond for a total writing time of 50 microseconds. The 70-mm wide film used provides large images which enhance the accuracy in the data reduction. Typical test results obtained with this camera are shown in Figures 8 and 9.

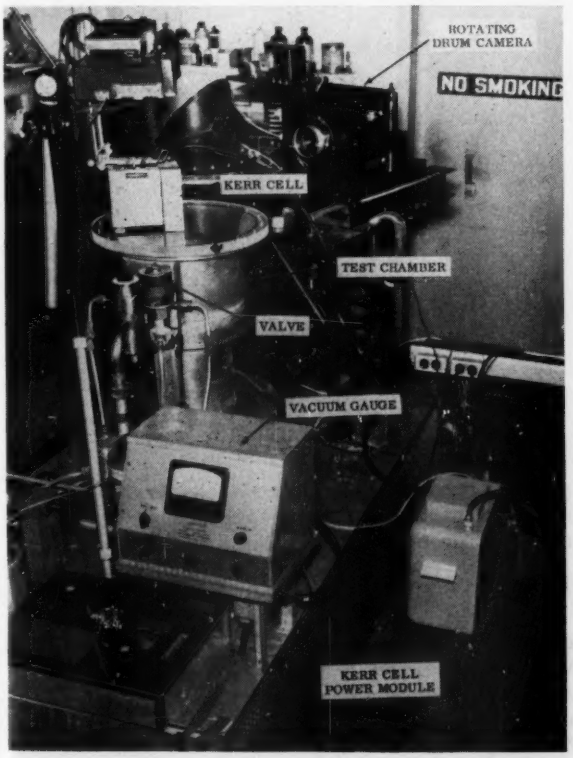


Figure 7. Instrumentation on Test Rig No. 1.

Light Probes

Two photocells (1P42) spaced a known distance apart have been used to determine the leading edge plasma velocity leaving a given nozzle as well as plasma front velocity distribution beyond the nozzle

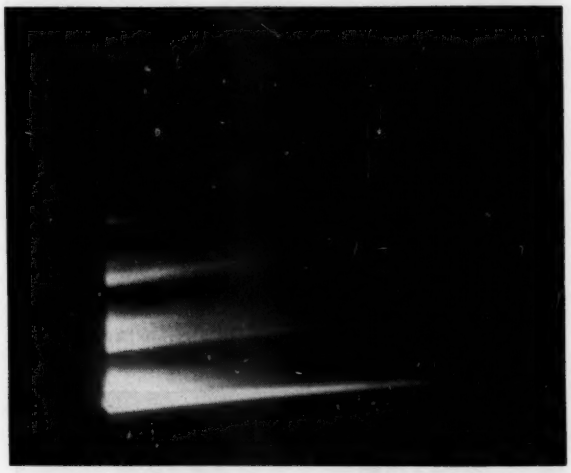


Figure 8. Typical Streak Photograph—Film Motion Perpendicular to Thrust Axis.

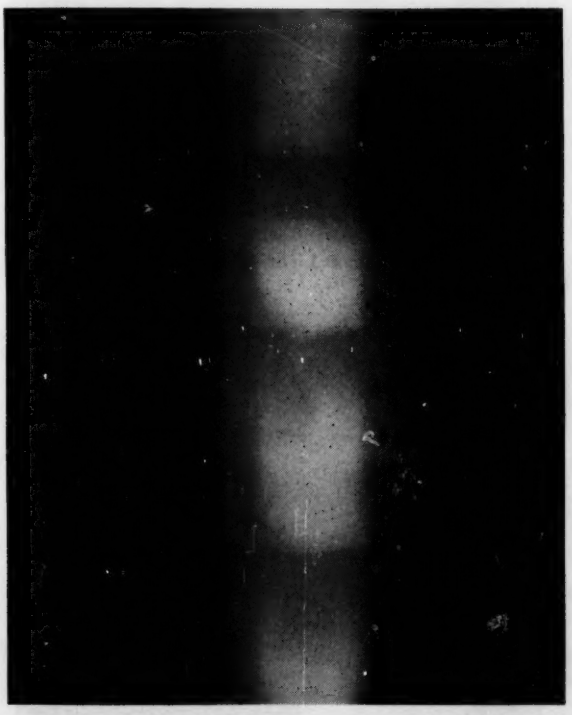


Figure 9. Typical Streak Photograph—Film Motion Parallel to Thrust Axis.

exit. The technique used is essentially that employed by other investigators in the field of plasma physics. This technique has been refined considerably through the extensive use of light shields, long light tubes and electrical shielding. A typical light probe installation is shown in Figures 10, 11, and 12. A typical result is shown in Figure 13.

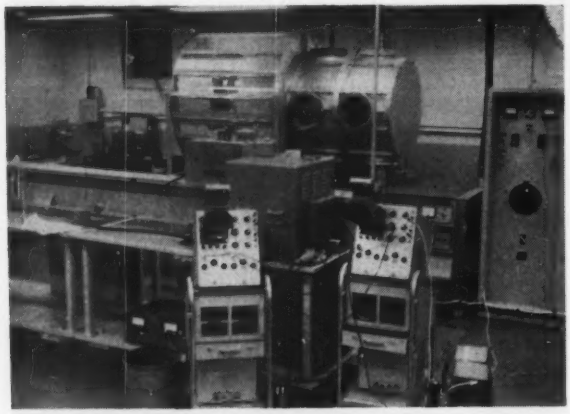


Figure 10. Light Probe and Instrumentation Arrangement —Test Rig No. 2.

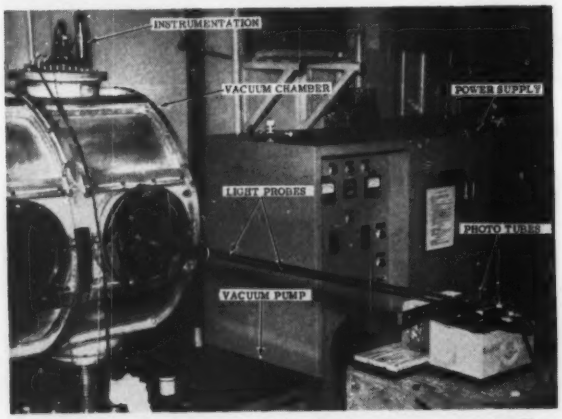


Figure 11. Close-up of Light Probe Arrangement—Test Rig No. 2.

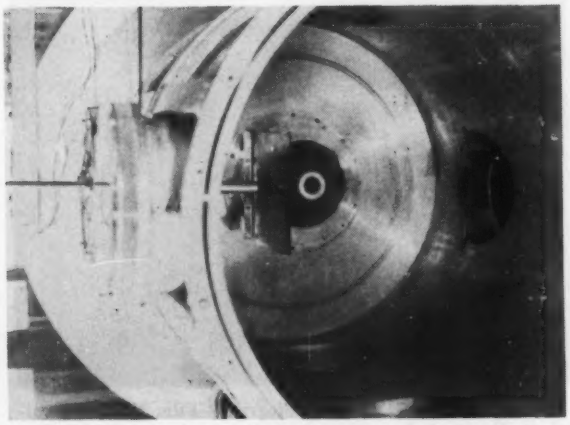


Figure 12. Interior of Test Chamber—Test Rig No. 2.

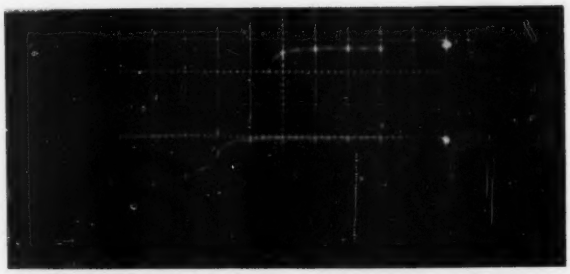


Figure 13. Typical Oscilloscope Traces from Light Probes.

Magnetic Probes

Small diameter, electrostatically shielded coils are being used at Republic to probe the magnetic fields set up during pinch discharges. This technique is well known and has been used extensively in thermonuclear work. From the voltages induced in the probes, information can be obtained on the magnetic pressure, the skin thickness, electrical conductivity of the plasma and velocity of the plasma motion. A typical magnetic probe is shown in Figure 14. Probe calibration tests are still in progress. The magnetic probe calibrating rig is composed of a parallel rail plasma accelerator located in a vacuum chamber. This calibrating rig with the magnetic probe in place is shown in Figure 15.

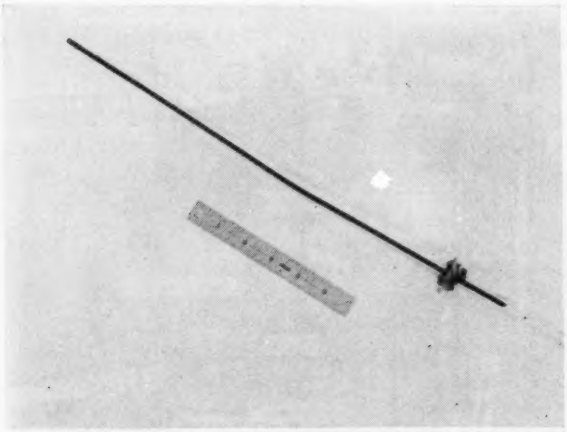


Figure 14. Magnetic Probe.

Thrust Measuring Devices

To obtain some quantitative data on the thrust developed by Test Rig No. 2 a ballistic pendulum was designed and tested at Republic. Figure 16 shows this pendulum installed over the nozzle exit of a typical nozzle. The pendulum deflection as a function of the capacitor energy being discharged per unit mass of propellant being accelerated is shown in Figure 17. Since a ballistic pendulum can

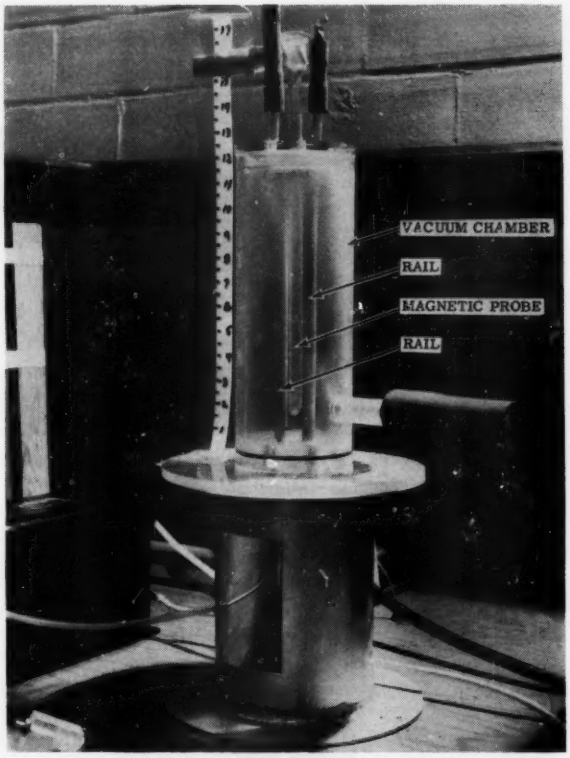


Figure 15. Bench Rig for Calibration of Magnetic Probes.

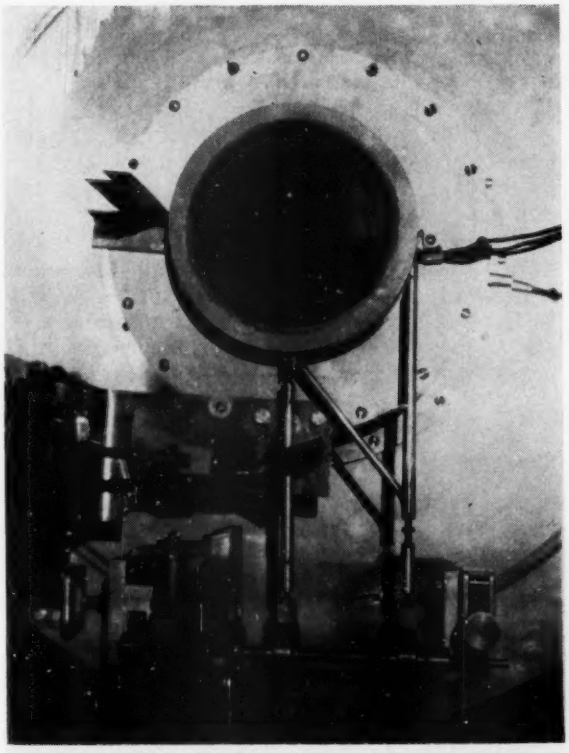


Figure 16. Ballistic Pendulum Mounted in Test Rig No. 2.

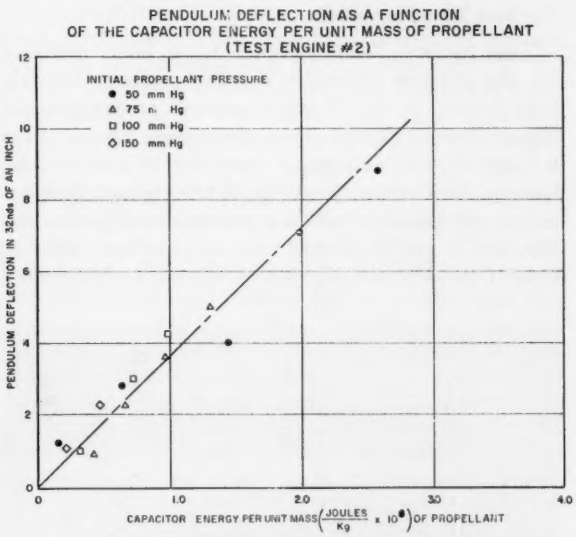


Figure 17. Ballistic Pendulum Test Results.

never truly give correct thrust readings of a pulsed plasma accelerator, work is now in progress to suspend a self contained plasma pinch engine on a pendulum type thrust stand. The engine and the thrust stand will be mounted in a large vacuum chamber. The latest design of the thrust stand will support the engine in an inverted vertical cantilever fashion on modular flexures. The restoring moment of the flexures is counteracted by an adjustable counterpoise. An adjustable damping unit will also be provided. This instrument, shown in Figure 18, will provide accurate readings of the thrust developed by the plasma pinch engine taking into account the thrust developed by the momentum efflux as well as the pressure forces generated. Based upon these thrust measurements the ballistic pendulum will be calibrated.

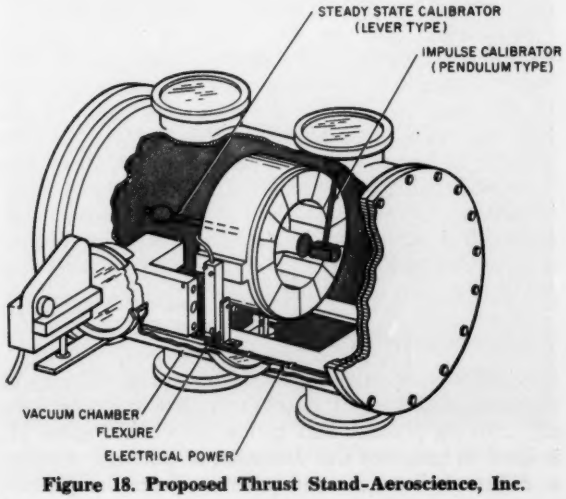


Figure 18. Proposed Thrust Stand-Aeroscience, Inc.

Surface Thermocouples

Two surface thermocouples have been obtained for the purpose of measuring the surface temperature as well as for "time-of-arrival" measurements. These thermocouples have a response of less than a microsecond. This rapid response is achieved by having the thermal junction of the surface thermocouple at the interface of a polished coaxial assembly and a junction thickness of only one micron. One of these thermocouples is shown in Figure 19.

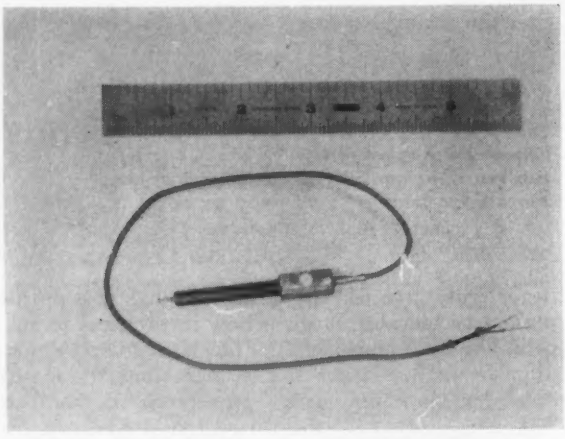


Figure 19. Rapid Response Surface Thermocouple.

Schlieren Shadowgraph System

The Schlieren Shadowgraph system shown in Figure 20, has been designed and built to study the flow of moving plasma in the region of objects inserted in its path and to obtain density gradients in various regions of flow. Furthermore, the equipment can be used to analyze the flow and distribution of gases between electrodes and also in the vacuum chamber in the absence of an electrical discharge. This system is designed to contribute information to improve the design of gas triggering equipment (to aid in the establishment of the best time for pinch or discharge after gas injection and to give indications of the rate of expansion of gas into the vacuum chamber). This system will be used in conjunction with a pulsed Kerr Cell to map flow and density patterns at precise times after initiation. Streak back lighting has also been attempted. A Kerr Cell having an effective exposure time of five millimicroseconds mounted on Test Rig No. 1 is shown in Figure 7.

Velocity Spectrometer

A probe was developed to discern the velocity of electrons and ions in a localized area of a low density moving plasma. This probe, shown in Figure 21, is used to map out the variation of particle velocity at different distances and positions from the plasma

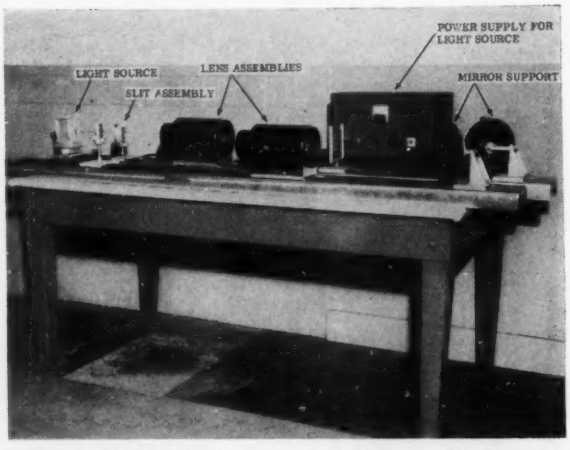


Figure 20. Bench Arrangement-Schlieren Shadowgraph Apparatus.

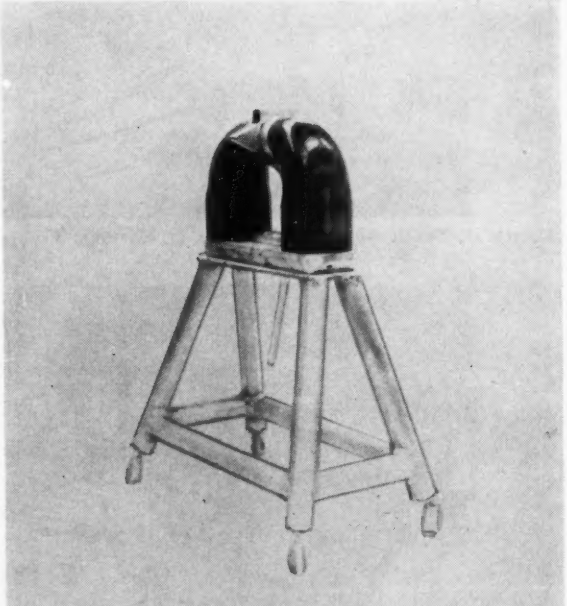


Figure 21. Velocity Spectrometer.

source. To accomplish this, a narrow beam of plasma is directed into a cavity across which a magnetic field is applied. The field causes separation of particles to either side of the beam, according to their charge. Two plates are placed in the paths of the particles, one for the negative stream and one for the positive. A "stopping" potential can now be applied to each plate and by variation of the potentials the particles can be stopped. From the potentials applied, an estimate can be made of the particle speed. The plot of the percentage of par-

ticles stopped for each applied potential gives an indication of the distribution of velocities within the sample taken.

Experimental Results

In this section, specific experimental results are cited which were obtained at the Plasma Propulsion Laboratory, and which are pertinent to the understanding and evaluation of a space propulsion system utilizing the pinch process.

Plasma Velocity

One of the significant parameters of interest in a propulsion system is the plasma velocity. To date the principal methods of measuring the plasma velocity have been streak photography and light probe measurements. These techniques, which are commonly accepted in the field of plasma physics, can only be reliably used to measure the velocity or time of arrival of luminous fronts. At Republic, the plasma velocity has been measured both in the inter-electrode space and at the exit of electrode nozzles. For plasma velocity measurements in the inter-electrode space, slots and light shields have been incorporated in a nozzle set (see Figure 11), and streak photography was employed. A typical streak protograph taken in a set of parallel plate electrodes is shown in Figure 22. From the slope of the luminous trace the plasma velocity at any section along the nozzle has been evaluated. While these measurements are important for understanding the physical flow processes inside a given nozzle, for propulsion purposes it is more important to know the plasma velocity leaving the nozzle. To measure the velocity of the exiting plasma, both streak photography and spaced light probes were employed.

In streak photography, information on plasma motion can be obtained either by moving the film normal or parallel to the plasma motion. Both techniques have been employed at Republic. Motion of the film normal to the exiting plasma provides information on plasma velocity analogous to that obtained in the inter-electrode space of the nozzles. Figure 8 is a typical streak photograph obtained with the rotating mirror camera with the film motion normal to the direction of plasma flow. Such traces have been used to evaluate the plasma velocity at the exit and beyond the exit of the nozzle. Velocities evaluated by this technique have been found to be consistent with those obtained using spaced light probes at and beyond the nozzle exit.

By properly arranging the rotating mirror camera, it has been possible to obtain photographs with the film motion parallel to the direction of the exiting plasma. This technique has yielded interesting and significant information on the electro-gas dynamical interactions. Figure 9 shows a typical result, and it will be noted that the pinch discharges are well defined and discrete.

As mentioned above, plasma velocity determined by spaced light probes gave results consistent with those obtained by use of streak photography. Since more data can be had in a given time with spaced light probes, this latter technique has been used predominantly for rapid comparisons of the effect of various nozzle contours on ejected plasma velocity. With the spaced light probe installation referred to under diagnostic devices, consistent results have been obtained. Figures 23 and 24 show the test results with current and light probe traces, respectively, taken at the same time. To show repeatability, the top trace of each figure has five consecutive traces superimposed on each other; the

Figure 22. Typical Streak Photograph of Radial Pinch Motion.

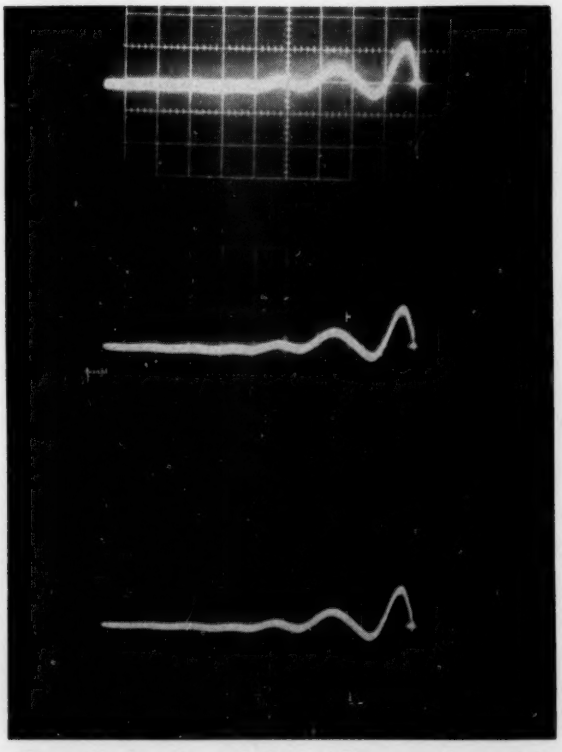


Figure 23. Superimposed Current Traces to Demonstrate Reproducibility.

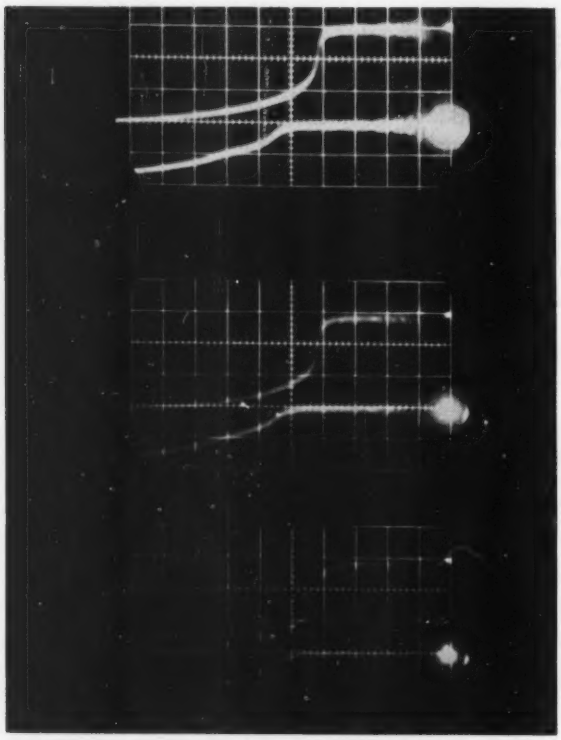


Figure 24. Superimposed Light Probe Traces to Demonstrate Reproducibility.

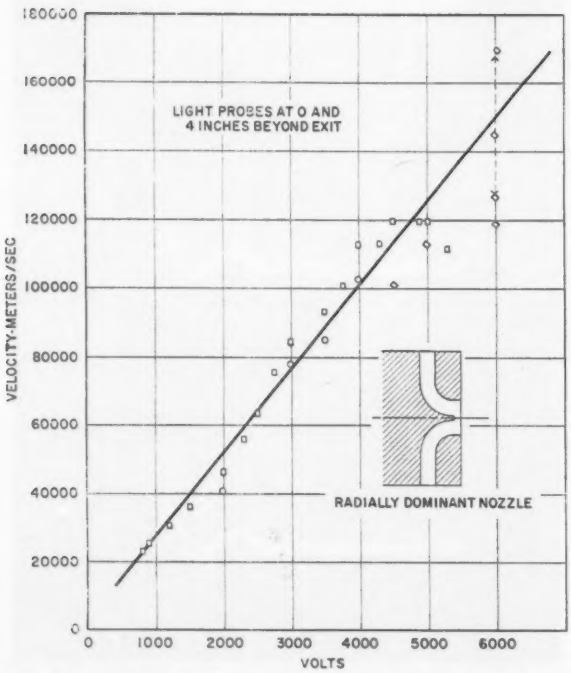


Figure 25. Velocity as a Function of Voltage for Radially Dominant Electrodes.

center trace has two consecutive traces superimposed and the lower trace is a single trace. Repeatability of test results has been definitely established. From the known spacing of the light probes, the sweep speed of the oscilloscope and the delay in the signal shown in Figure 24, the average plasma velocity is readily determined.

Figures 25 through 30 show the experimental results obtained at Republic with various electrode nozzle contours as tested in Test Rig No. 2. These figures present the exit velocity in meters per second as a function of the voltage applied to the electrode nozzles. The capacitance used was 300 microfarads in all cases. Two of the many nozzles tested are shown in Figures 31 and 32. From these results

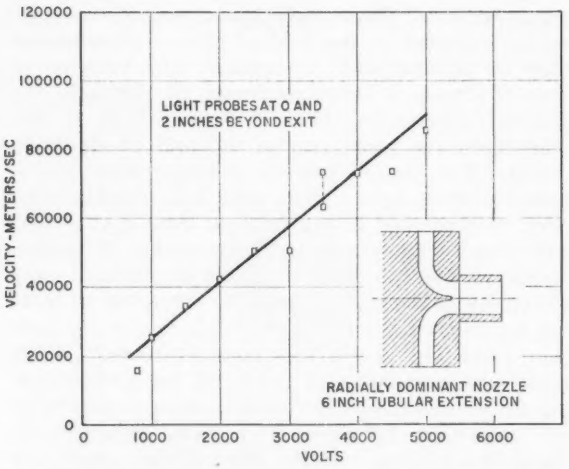


Figure 26. Velocity as a Function of Voltage for Radially Dominant Electrodes Fitted with a 6" Tubular Extension.

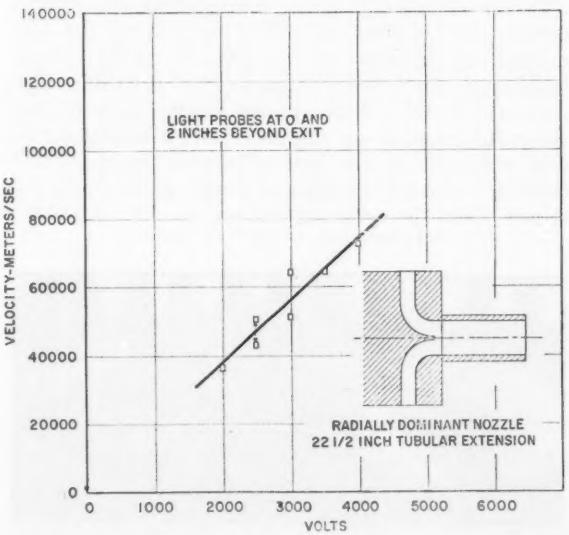


Figure 27. Velocity as a Function of Voltage for Radially Dominant Electrodes Fitted with a 22½" Tubular Extension.

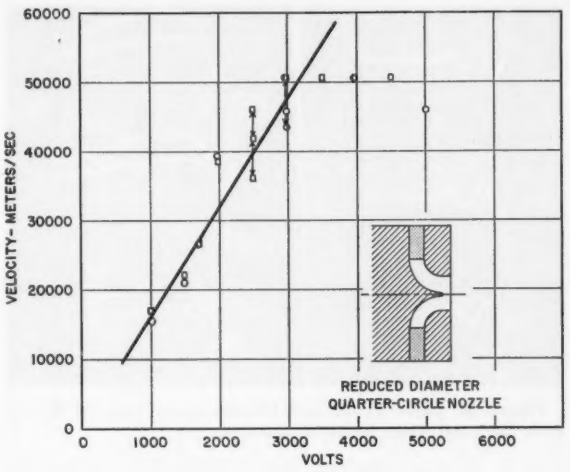


Figure 28. Velocity as a Function of Voltage for a Reduced Diameter Quarter Circle Electrode.

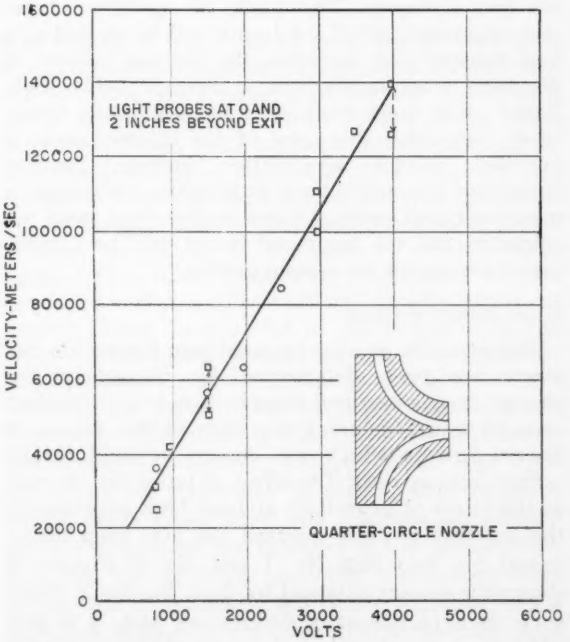


Figure 29. Velocity as a Function of Voltage for a Quarter Circle Electrode.

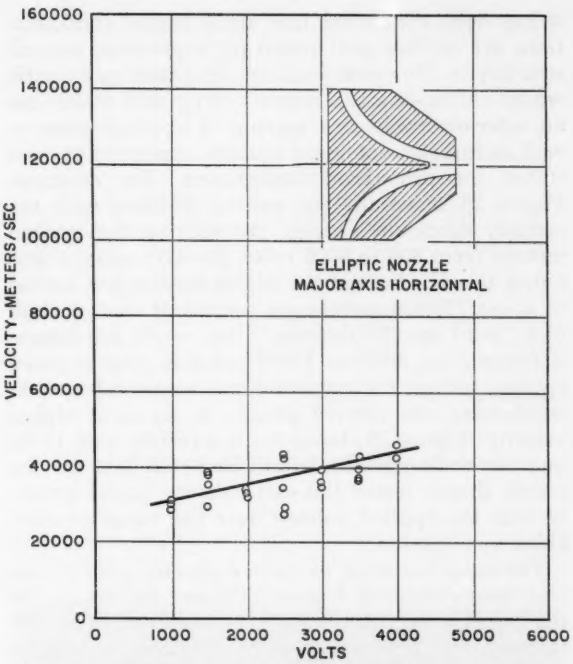


Figure 30. Velocity as a Function of Voltage for an Elliptic Nozzle with the Major Axis Horizontal.

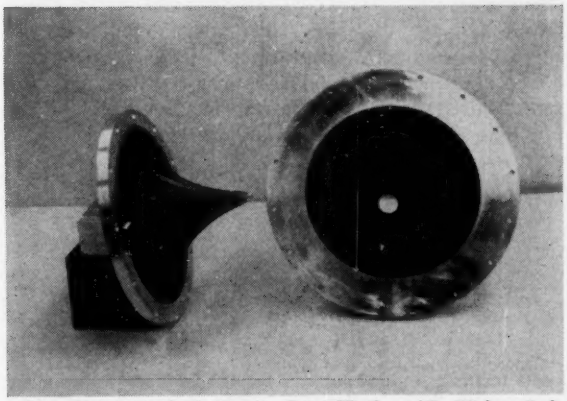


Figure 31. Typical Nozzle Set-Elliptic with Major Axis Horizontal.

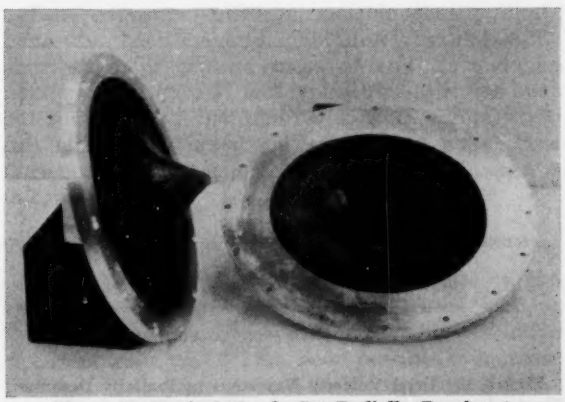


Figure 32. Typical Nozzle Set-Radially Dominant.

it has been concluded that some nozzle configurations are not too well suited for a practical propulsion device. However, such configuration as a nozzle whose center-line is a quarter circle and which has an inter-electrode gap spacing of one-half inch, as well as radially dominant nozzles, appear to be well suited for propulsion applications. For example, Figure 25 shows the test results obtained with the radially dominant nozzles. By varying the applied voltage from 800 to 6000 volts, the exit velocity was found to vary from about 20,000 meters per second to about 170,000 meters per second. If one can talk of a "local specific impulse," this would encompass a range from 2000 to 17000 seconds. For a given applied voltage the quarter circle nozzle referred to accelerated the ejected plasma to an even higher velocity. Figure 29 shows the test results with these quarter circle nozzles. It will be noted that for the nozzle shapes tested the exit velocity varied linearly with the applied voltage over the range of variables investigated.

The axial variation of ejected plasma velocity has also been measured. Figure 33 shows the results for the radially dominant nozzle at 3000 volts and 300 microfarads. The results were obtained by making measurements over a 0-2, 0-4, 0-6, 0-8 inch spacing, as well as measurements from 0-2, 2-4, 4-6, 6-8 inch spacing beyond the exit of the nozzle. From these data it appears that the velocity as indicated by the light probes decays rapidly in the axial direction.

Light probe traces on a slower oscilloscope time sweep are shown in Figure 34. Several discrete pinches can be observed to emerge from the nozzle exit, in accordance with streak photo results as shown in Figure 8 and 9.

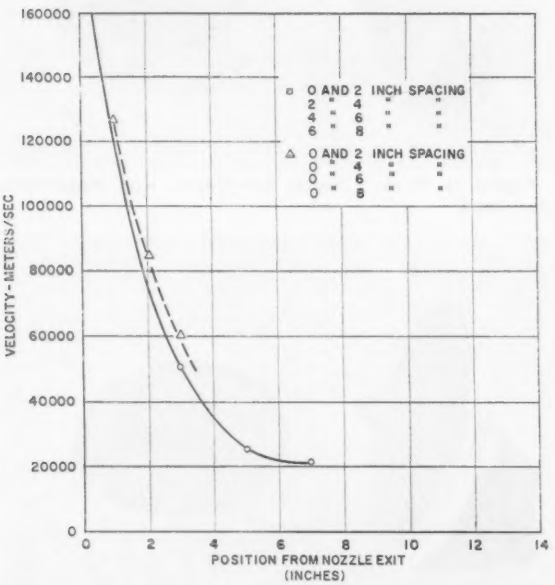


Figure 33. Axial Velocity Variation in Radially Dominant Electrodes.

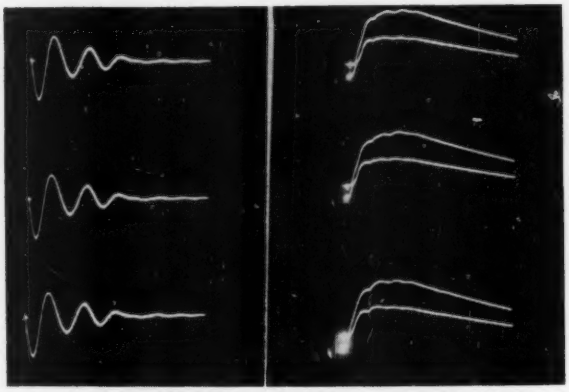


Figure 34. Light Probe and Simultaneous Current Traces with Reduced Time Scale-10 usec/cm.

It is also interesting to note that in Figure 33 the light probe indications of discrete pinches coincide very nearly with the time the current goes through zero. This and the streak photographs have furnished preliminary evidence that a new pinch is formed at the outer periphery each time the current goes through zero. Another conclusion is that any residual mass not picked up by the first pinch passing through the nozzle is picked up by the subsequent pinch and ejected at a velocity comparable to the mass ejected with the first pinch. Even though less energy is available to the second pinch, it must be remembered that less mass is available. Streak photographs such as Figure 8 show that the plasma velocity of subsequent pinches in a given electrical discharge is indeed comparable to that of the first discharge. This mode of operation shows that apparently all of the fronts will be ejected at a high velocity and, therefore, the average velocity of the total mass accelerated is also probably high. Based upon these studies, it has also been tentatively concluded that most of the injected mass is involved in the acceleration process. Further studies on this subject are in progress. Of course, a mass averaged velocity based on the total mass accelerated and the measured thrust will be a more useful parameter for system studies.

Mass Measurements

The quantity of mass injected into the nozzle per pinch has been determined by measuring the change in pressure and temperature in a propellant storage tank (including the lines to the valve) of known volume which was chosen to yield results within five per cent. The effect of pulse rate as well as the effect of propellant storage tank pressure on the quantity of mass injected has also been determined for Test Rigs No. 1 and No. 2. Figure 35 shows the results obtained for Test Rig No. 2. From such an experimentally determined plot, it is possible to obtain the total quantity of mass injected per pinch. It was furthermore desirable to learn

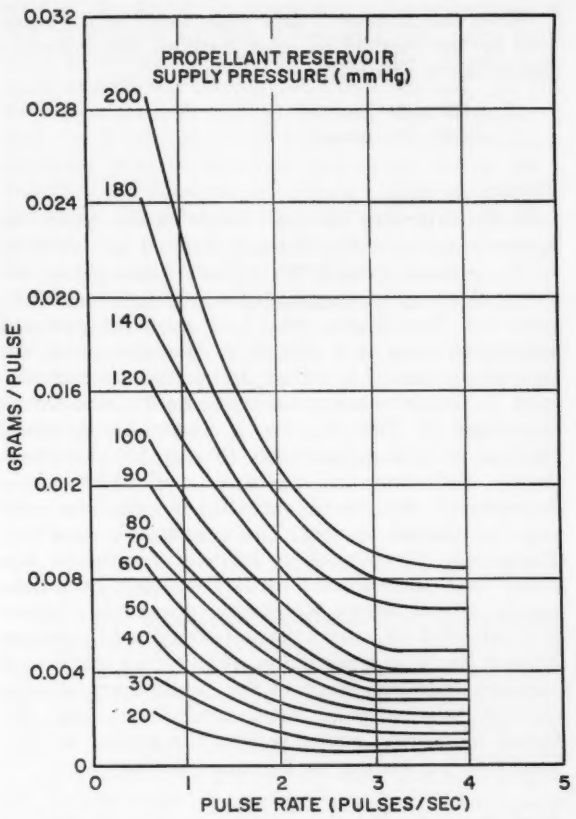


Figure 35. Valve Calibration for Injected Mass Determination.

how much of this injected fluid would leak from the exit of the nozzle before the pinch arrived. For this purpose, tests have been carried out with a setup shown schematically in Figure 36. In these tests the elapsed time between the opening of the propellant valve and the initiation of the pinch was compared with the elapsed time between the opening of the propellant valve and the arrival of the injected propellant at the exit of the electrode nozzle. This latter time was determined by the breakdown of a small auxiliary parallel plate capacitor placed at the exit of the nozzle with the plane of the plates parallel to the flow direction. The breakdown occurred because of a pressure rise between the plates. This auxiliary capacitor was previously calibrated to determine its own pressure-voltage breakdown characteristics. The voltage across this probe was adjusted so that the probe would break down when the pressure increased a few microns above the pressure in the vacuum surrounding the electrode assembly. These tests have shown that it is possible to operate Republic's plasma pinch engine in a manner that essentially none of the injected propellant is lost prior to the pinch arriving at the exit plane of the nozzle.

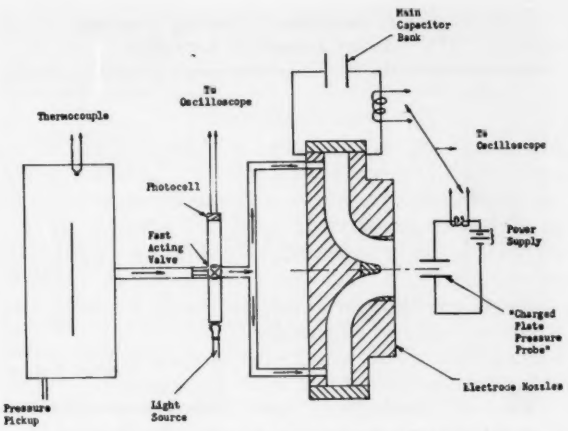


Figure 36. Schematic of Mass Utilization Program.

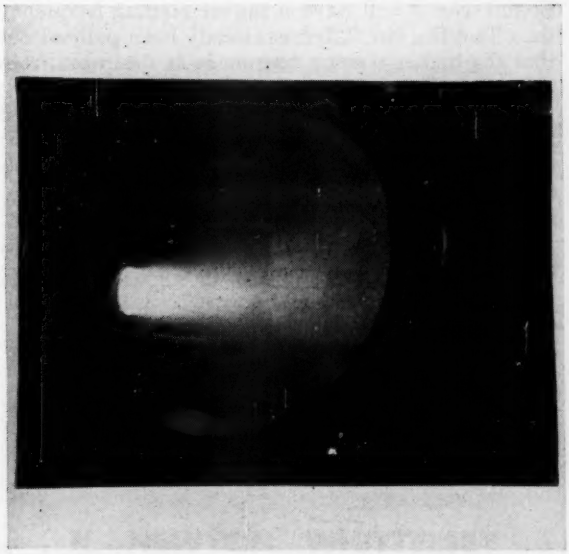


Figure 37. View of Ejected Plasma Using a Newtral Density Filter.

Time exposures utilizing variable density filters have also been used to qualitatively examine the distribution of plasma mass at and beyond the nozzle exit. Figure 37 is a typical result. It has been determined that the plasma ejected occupies the full nozzle exit area and experiences very little flare-out in the vacuum into which the plasma is injected.

Electrodynamic Parameters of the System

The frequency of discharge of the circuit can readily be evaluated from current traces such as those of Figure 23. Through a systematic reduction of circuit inductance it has been possible to increase the ringing frequency from 25 Kc for Test Rig No. 1 to about 50 Kc for Test Rig No. 2. Prototype Test

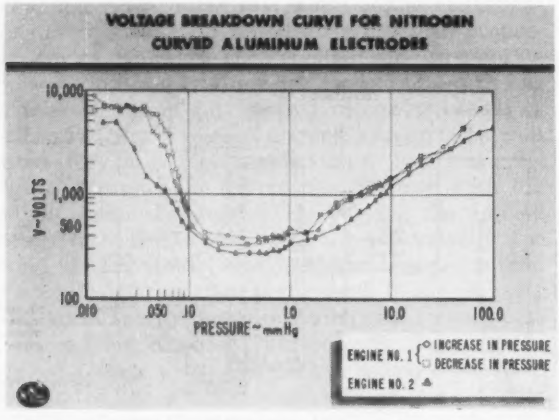


Figure 38. Voltage Breakdown Curve for Nitrogen-Test Rigs No. 1 and 2-Radially Dominant Aluminum Electrodes.

Engine No. 3 will have a higher ringing frequency than Test Rig No. 2. It has already been pointed out that the higher ringing frequency is desirable from the point of view of pinch initiation.

The inductance of Test Rig No. 2 was calculated from measurements of the ringing frequency, f, as the capacitor bank was decreased from 10 capacitors to 5 capacitors. (The capacitors were 30 microfarads each.)

It was assumed that the resistance of the rig was negligible and that the inductance, L, is given by:

$$L=\frac{L_c+L_e}{n}$$

Where

L_c = inductance of a single capacitor and its connecting cable
L_e = inductance of the remainder of the circuit
n = number of capacitors in the bank

When the measured data were fitted to the equation by the method of least squares, the following values were obtained.

$L_e = 1.56\times10^{-8}$ henrys
$L_c = 2.43\times10^{-7}$ henrys

Thrust

Early estimates of the thrust were based on knowing the quantity of mass injected and velocity of the plasma ejected. To further demonstrate the thrust-developing capabilities of the vertically mounted Test Engine No. 1, a specially designed lightweight cup was placed in the stream of the ejected plasma. This technique had many shortcomings. To obtain some quantitative data of the thrust developed by Test Rig No. 2, a specially designed ballistic pendulum was used (Figure 16). The pendulum deflection was measured and plotted as a function of the stored capacitor energy per unit mass of plasma ejected. The results are shown in Figure 17. Since such a ballistic pendulum can never truly measure the thrust developed by a nonsteady pulsed device ejecting compressible plasma, it is intended to mount the self-contained Prototype Engine No. 3 on a pendulum type thrust stand in a vacuum chamber. Most of the preliminary studies on this have already been carried out, and the thrust measuring device referred to earlier will be available for testing in the near future.

Pinch Initiation

In the Republic pulsed plasma pinch engine, the pinch is initiated by the injection of gas into the inter-electrode space near the outer periphery. For both a fundamental understanding of the formation of the pinch as well as to obtain data necessary for the reliable operation of the engine, experimental

TABLE I—(TEST RIG No. 2)

Study of Low Energy Pinches To Relate the Pinch Plasma Phenomena To Discharge Energy and Current

Run No.	C (uf)	V (volts)	P_1 (mm Hg)	P_2 (mm Hg)	$CV^2/2$ (Joules)	Total Injected Mass (10^{-6} Kg)	Pinch	Remarks
1	120	2500	50	0.2	375	2.87	yes	asymetrical
2	120	3000	50	0.2	540	2.87	yes	symetrical
3	120	3500	50	0.2	735	2.87	yes	asymetrical
4	120	2500	70	0.2	375	3.84	yes	asymetrical
5	120	3000	70	0.2	540	3.84	yes	symetrical
6	120	3500	70	0.2	735	3.84	no data	see item 6A
7	120	1500	100	0.2	135	5.75	no	no data
8	120	2000	100	0.2	240	5.75	no	no data
9	120	2500	100	0.2	375	5.75	yes	symetrical
10	120	3000	100	0.2	540	5.75	yes	asymetrical
10A	120	3500	100	0.2	735	5.75	yes	no data
6A	120	2500	100	0.2	735	5.75	yes	repeat of item 6

P_1 Inlet Pressure (mm Hg)
P_2 Chamber Pressure (mm Hg)

studies on the initial breakdown characteristics of the propellant in the inter-electrode space have been performed. Figure 38 shows the voltage-pressure breakdown curves (Paschen curves), for the radially dominant nozzles in both Test Rigs No. 1 and No. 2 with nitrogen under static conditions. It has also been determined that these curves are a function of the electrode surface conditions and the gas used. By reference to these curves it has been possible to predict the proper operating voltage levels for the case of injected propellant.

Since efficient energy utilization is obviously of importance to a space propulsion device, an effort has been made to study the minimum energy requirements for a pinch as a function of system requirements. Table I shows some of the data from these studies taken on Test Rig No. 2 with a constant capacitance of 120 microfarads. This table shows whether a pinch was formed at all and the type of pinch, all based upon streak photographs of the inter-electrode space. Data on other gases and gas mixtures have also been taken as part of this overall program.

The third item under the heading of pinch initiation that has been investigated is the study of time lags in gaseous discharges. Preliminary work reported in Republic's AFOSR TN-60-59 [1] indicates that the time lag in the discharge is a function of capacitor energy, pressure and type of gas. It was concluded that the greater the capacitor energy and gas pressure the shorter the time lag. There is also a sharp decrease in the time lag once a critical capacitor voltage is exceeded.

The entire program of pinch initiation is a continuing part of the fundamental and applied studies being investigated in the Plasma Propulsion Laboratory.

ACKNOWLEDGMENT

The authors wish to acknowledge the invaluable aid of Messrs. C. C. Cavalconte and A. Steinberg in devising some of the test equipment, setting it up, and in carrying out some of the work described in this report. In addition, the cooperation of Messrs. William Johnson, H. Latz, and E. Poggi in the execution of this program is gratefully acknowledged. Since it is not possible to mention by name all of the personnel who individually contributed in some measure to this work, the writers take this opportunity to collectively thank them.

This work was sponsored in part by the Office of Naval Research under Contract Nonr-2851(00) and in part by the Air Force Office of Scientific Research under Contract AF49(638)-552.

REFERENCES

[1] Granet, I., Guman, William J., and McIlroy, W., "Studies of a Plasma Pinch Space Engine," *ASNE Journal*, November 1960, pp. 715-725.
[2] Unterman, M., Republic Aviation Corporation, Plasma Propulsion Project Private Communication.
[3] McIlroy, William, Republic Aviation Corporation, Plasma Propulsion Project, Private Communication.
[4] Donner, T. and Aronowitz, L., "Experimental Investigations of Electromagnetically Induced Detonations—Part I—Parameters Affecting the Formation of the Pinch," AFOSR TN 60-59 November 1959.
[5] Granet, I. and Guman, William J., "A Review of Republic's Pinch Engine Experimental Program," PPL-60-15 (160) October 21, 1960 ONR.

NAVAL ARCHITECTS
MARINE ENGINEERS

M. ROSENBLATT & SON, Inc.

NEW YORK CITY
350 BROADWAY
BEekman 3-7430

SAN FRANCISCO
216 MARKET ST.
EXbrook 7-3596

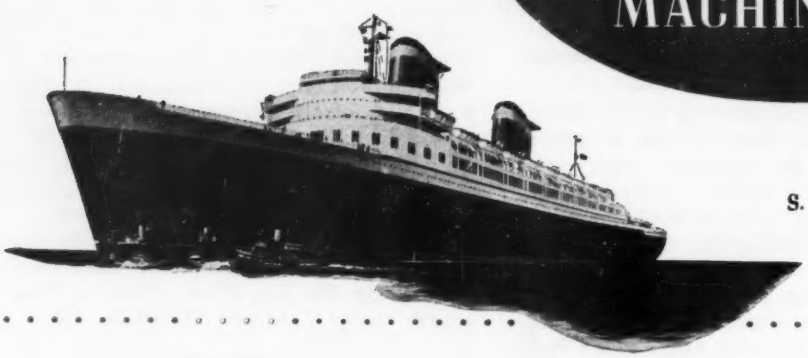
H. NEWTON WHITTELSEY
Inc.

NAVAL ARCHITECTS MARINE ENGINEERS

17 BATTERY PLACE, NEW YORK 4, N. Y.
WHitehall 3-6280 Cable: WHITSHIP

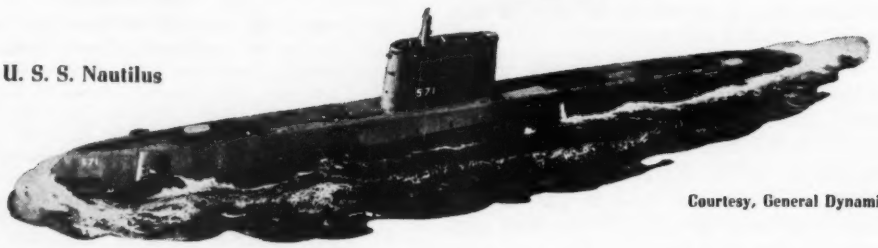
The PRECISION GEARS which Drive these Great Ships were Finished on . . . . . .

RED RING HORIZONTAL SHAVING MACHINES



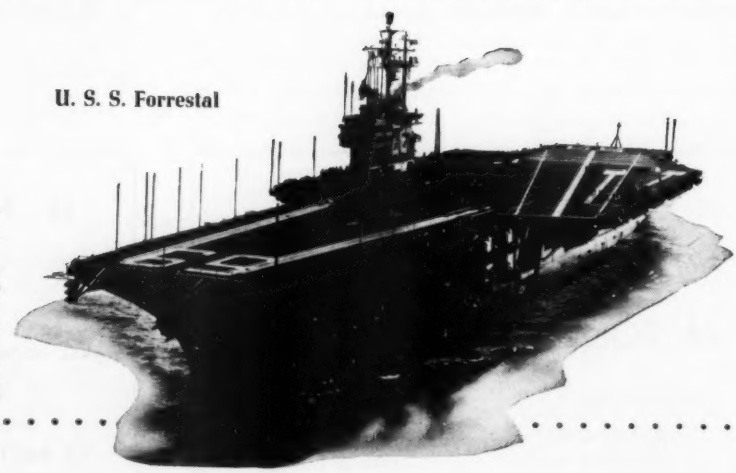
S. S. United States

U. S. S. Nautilus



Courtesy, General Dynamics Corporation

U. S. S. Forrestal



Red Ring horizontal rotary shaving machines were used by Westinghouse Electric Corporation to finish the main propulsion gears of these great ships and many others.

Rotary Shaving assures precision in external and internal gears of all sizes. Write for information on your gear problems.

SPUR AND HELICAL GEAR SPECIALISTS
ORIGINATORS OF ROTARY SHAVING
AND ELLIPTOID TOOTH FORM

NATIONAL BROACH & MACHINE CO.

5600 ST. JEAN • DETROIT 13, MICHIGAN

7693

WORLD'S LARGEST PRODUCER OF GEAR SHAVING EQUIPMENT

"FRONTIER"

ELECTROMAGNETIC COMPATIBILITY

ACKNOWLEDGMENT

This article was written by Stanley I. Cohn, director of technical operation for the Electromagnetic Compatibility Analysis Center referred to in the article. It appeared in the Armour Research Foundation publication "Frontier," summer 1961 issue, from which it is reprinted.

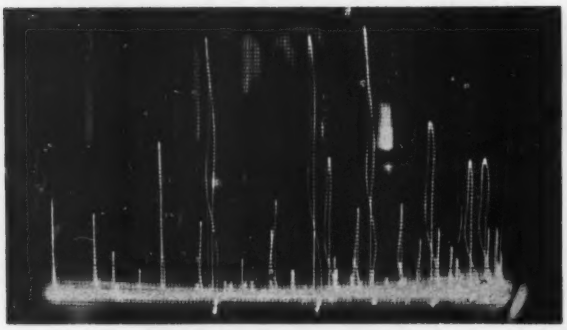
CAN WE AFFORD to crowd ourselves out of the radio frequency spectrum?

Today that is the most pertinent question in the electronic field where radio frequency interference (RFI), which has always been an annoyance, has now become a major problem. With the ever-increasing number as well as the growing sensitivity of electronic installations, radio interference problems have multiplied drastically. Missile failures, communication jamming, radar blanking, collisions at sea and in the air are but a few of the catastrophes directly traced to RFI.

Since the early days of wireless communication at the turn of this century, interference has created an annoyance in one form or another. In those days, moving to an unused higher frequency provided a temporary solution. This practice alone was primarily responsible for the exploration of new frequency spectra constantly moving toward the wavelength of light. By the early 1920's the frontier had been pushed to the 10 megacycle range. By the early 1930's, to the 30 megacycle range. And by the early 1940's, developments in the 200-600 megacycle range were well established. The advent of World War II was accompanied by an additional push of the spectrum to accommodate new forms of information retrieval, such as radar.

On the heels of increased spectrum development for relief of congestion came two more factors that compounded the problem at a tremendous rate. To obtain greater range both transmitter power and receiver sensitivity were increased. These factors contributed significantly to the RFI problem.

Although the compounded results are obvious, integrated efforts to overcome the mounting difficulties have evolved slowly. During the late 1940's the problem was recognized by various groups both in the military and in industry. Generated out of the resulting concern was a tri-service contract issued to the Armour Research Foundation in 1953. It was initiated to determine the magnitude of the problem, to obtain recommendations for investigation in



Panoramic display of a portion of the spectrum at Cape Canaveral seen on a spectrum analyzer, showing amplitude of signals in a 160 megacycle band. Crowded conditions that contribute to the compatibility problem at this vital military base are clearly indicated.

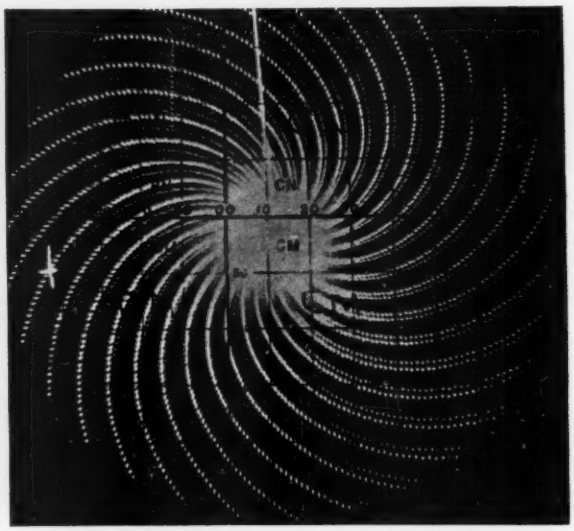
technical and administrative areas, and to obtain recommendations for establishing a suitable interference reduction program.

Additional orientation on interference came in 1954 through the organization of the First Conference on Radio Frequency Interference, jointly sponsored by government agencies and ARF. Other similar conferences have since taken place, and important advances have been made in suppression techniques.

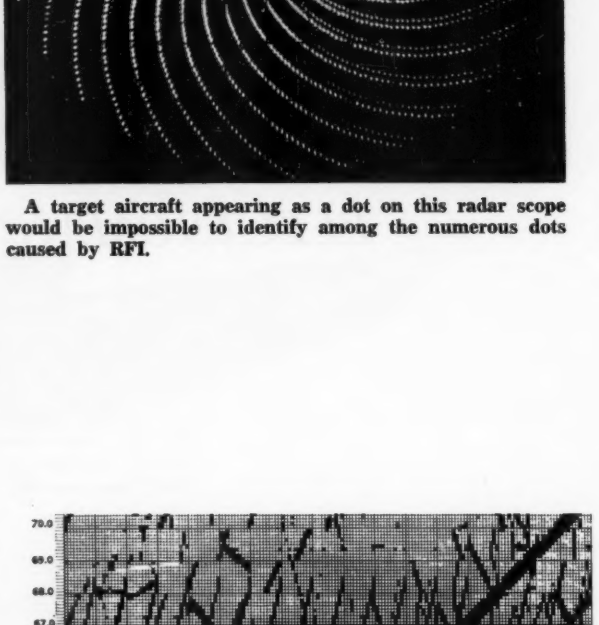
The most significant move toward the control of RFI, however, is evolving out of the decision of the Department of Defense (DOD) to unify the efforts of all three services in an overall electromagnetic compatibility program. At the hub of this program is the establishment of the Electromagnetic Compatibility Analysis Center at the U.S. Naval Engineering Experiment Station in Annapolis, Md. The technical operation of this facility is to be conducted by ARF, which has been awarded a $2 million contract for this purpose by the Electronic Systems Division (Hanscom Field, Mass.) for the Air Force Systems Command.

The activities of the Analysis Center will necessarily focus on determining the degree of electromagnetic compatibility—i.e., interference-free operation—in existing and proposed military situations. The degree of compatibility, however, is not the only concern. What must be resolved is the realization of electromagnetic compatibility for a given military situation. To this end, the Analysis Center will team technical and administrative talent for developing and applying techniques relevant to the solution of an immense accumulation of existing and forthcoming RFI problems.

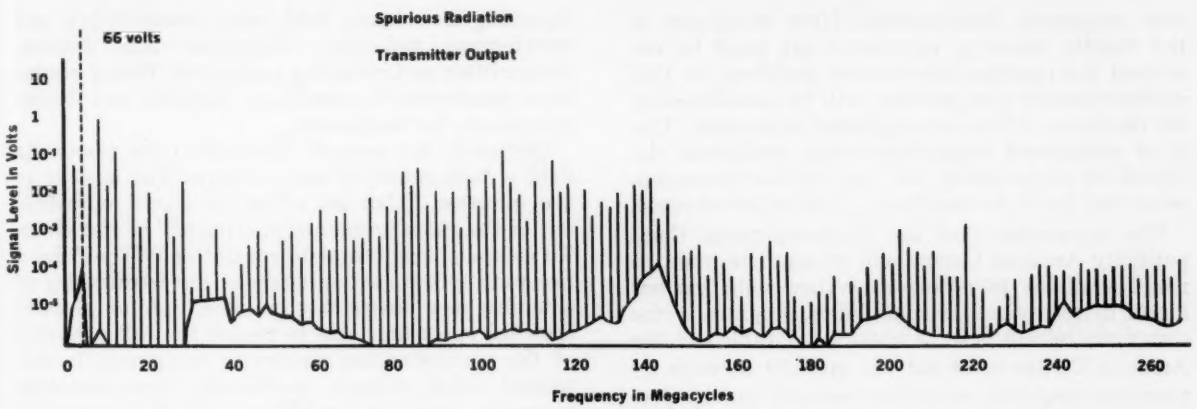
This facility will include not only 80 to 90 technical personnel trained in the use of electronic and mathematical techniques, but also a large digital computer facility. The Analysis Center will be responsible to the DOD through a director supplied by the military. The director will report to the DOD



A target aircraft appearing as a dot on this radar scope would be impossible to identify among the numerous dots caused by RFI.



Blackened areas on mutual interference chart indicate frequencies at which interference will occur at the receiver for any given transmitter frequency. Chart is read by selecting a transmitter frequency (*at right*), moving across the chart and noting which receiver frequencies correspond to the darkened areas.



Graph demonstrates the amplitudes of the undesired frequencies generated by a radio transmitter. Ideally, transmitter would generate energy at the assigned frequency of four megacycles rather than spurious energy over the wide range shown.

and the Joint Chiefs of Staff. The Army, Navy, and Air Force will each have a support group that can contact the Analysis Center directly with problems.

Assistance in establishing the Electromagnetic Compatibility Center will be provided by the Engineering Experiment Station of Georgia Institute of Technology, which has been subcontracted for this endeavor by ARF.

To understand the various functions that must be performed at the Center, it is best to consider first the given input and output information required. Input information consists basically of military situations and equipment deployment (environmental data) as well as the data regarding the characteristics of electronic equipment (spectrum signatures). The required outputs are descriptions of environmental interaction, frequency allocation data, operational procedures needed to increase compatibility, and possible interference and susceptibility reduction measures for offending equipment. From these results better utilization of the radio frequency spectrum, both in the frequency allocation and equipment characteristics areas, should be obtained. Although initial emphasis will be placed on radar, the Analysis Center will eventually attack problems in the communication area.

Since the spectrum signatures of equipment are rather complex and hand calculations of the interaction of equipment are quite lengthy, it is obvious that automatic processing must be used to evaluate compatibility in any realistic military situation. This requires that spectrum signatures and environmental data must be maintained in a central library in a form that is suitable for a computer. In order to process these data one must use a mathematical model which is a computer representation of the situation and physical phenomena to be analyzed.

Data processing techniques for analysis of compatibility are relatively new, and effort must be directed toward refining these and developing more sophisticated computer programs for analysis. In addition, techniques of operations research must be developed and applied to determine optimum frequency allocations and operational procedures that will enhance compatibility. Methods of handling the immensely complex results of the analysis must also receive consideration. This requires research in the application of data read-out systems, map printing, and environmental display techniques to facilitate comprehension of staggering quantities of interrelated data.

Another factor that will be considered is the validity of the data to be used. As experience is gained in compatibility analysis, the accuracy and types of data required will change in order to obtain more meaningful results. The Analysis Center staff must respond to these changes by aiding in revisions of data collection standards, both in the spectrum signature and environmental data areas. Measurement techniques must be reviewed and revised periodically, taking into account resulting data accuracy, ease of measurement, and instrumentation requirements.

It is anticipated that the analytical results will point up problems in equipment characteristics. Possible corrective measures for reducing interference susceptibility and undesired radiation must be proposed. These may take the form of equipment circuit modifications or addition of selective filters. In certain cases, it may be wise to replace certain types of equipment because of poor compatibility characteristics.

In the case of equipment under development, compatibility analysis can be a design aid by pointing out which equipment characteristics need improvement. Along these lines, technical personnel must not only be familiar with the state of the art in interference reduction but must also be aware of

new equipment developments. New techniques in the rapidly changing electronics art must be examined for possible interference problems so that electromagnetic compatibility will be considered by the designers of future complicated equipment. This is of paramount importance since equipment designed for compatibility will cost far less than equipment that has to be modified to reduce interference.

The knowledge that the Electromagnetic Compatibility Analysis Center will accumulate must be made available to others concerned with various facets of the overall compatibility program if the maximum benefit is to be obtained. To this end the Analysis Center must aid the military services by providing required consultant services and by preparing information to be included in manuals and specifications.

Anticipated areas of consultation include equipment standards, measurement techniques, instrumentation, data collection methods, interference reporting techniques, field tests, susceptibility and interference reduction techniques and devices, transmitting and receiving equipment, future equipment requirements, simulation methods, and design procedures for equipment.

Obviously the present dilemma in the electronic field is both extensive and intricate. The answer to the question, "Can we afford to crowd ourselves out of the radio frequency spectrum?" is also clear. To escape chaos, complete control of RFI will be a necessity in the coming years as the frequencies of countless new devices are crammed into an already crowded spectrum. And to realize the full potential of the ultra-sensitive electronic equipment in advanced radar systems, world-wide communication networks employing satellites, and in interspacial contact, we *must* obtain electromagnetic compatibility. The first major step toward this objective is the initiation of the DOD compatibility program and the establishment of the Electromagnetic Compatibility Analysis Center.

MOVABLE ARM FOR *TRIESTE*

The Navy's deep-diving bathyscaph ***Trieste*** is to be fitted with a movable arm that can reach out and pick up materials from the ocean floor during its exploratory dives. The mechanical arm manipulator is being manufactured by General Mills' Nuclear Equipment Department, Minneapolis, Minnesota.

The arm is being built to withstand pressures up to nine tons per square inch. The ***Trieste*** was subjected to a pressure of 7.9 tons per square inch during its record-breaking dive to 35,800 feet at the bottom of the Marianas Trench off Guam in the Pacific. The mark was set by Lt. Don Walsh USN and M. Jacques Piccard in January 1960.

The manipulator will be equipped with oil-filled units to equalize pressures on motors and other critical parts. It will provide six motions: grip; wrist; elbow and shoulder bending; and rotation of wrist and shoulder. It will be mounted directly ahead of the steel sphere suspended below the ***Trieste***. Men inside the sphere will control the arm by individual switches that provide direction and variable speed control for each motion.

The ***Trieste*** program is jointly sponsored by the Office of Naval Research and the Navy's Bureau of Ships.

HILBERT SCHENCK, JR.

THE DESIGN OF HEAT EXCHANGE SYSTEMS USING GRAPHS AND A MECHANICAL COMPUTER

THE AUTHOR

was born in Boston, Feb. 12, 1926. Attended primary schools in the New England area and served two years in the Navy during World War II as an electronic technician. Attended Williams College receiving a B.A. degree, then Stanford University for an M.S. in Mechanical Engineering. Employed for four years as a test engineer in heat transfer research at Pratt and Whitney Aircraft. Joined the staff of Clarkson College, Potsdam, New York as an Assistant Professor and was recently promoted to Associate Professor of Mechanical Engineering. Author of several papers and books on underwater visibility, photography and diving plus the book Heat Transfer Engineering *recently published by Prentice-Hall, Inc.*

INTRODUCTION

In the design of integrated thermal systems in modern aircraft, ships, and central station layouts, the engineer is increasingly confronted with problems in which several heat exchangers are interconnected and in which more than two fluid flows are involved. Consider, as a hypothetical example, a fictitious arctic installation which uses 300 F inlet hot water supplied by a nuclear heating plant to provide hot air for living spaces and also to heat a separate hot air stream which warms the hangars and shops. Because of ducting distance, the hangar air must be heated to 250 F and will return at 20 F while the nearer living areas require only 120 F air which returns at 60 F. Preliminary considerations lead us to the arrangement in Figure 1 in which three cross-flow, water-to-air heat exchangers are linked, with the water flowing through each in turn. The first and third units carry only the hangar air, while the center unit handles both the hangar and living spaces air. In a practical case, we might be given the air flows and wish to adjust the water flow to minimize both the size of the three units and the heating load on the reactor.

Similar classes of problems might occur in an air-

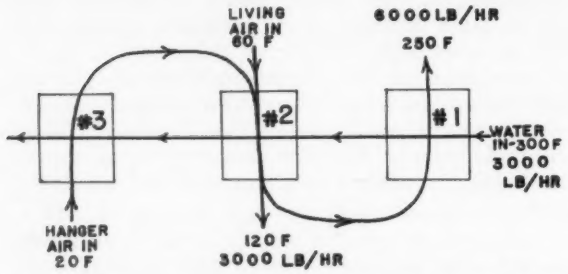


Figure 1. Flow diagram of a hypothetical space heating system having two air flows and a single hot water flow.

craft in which cabin-air, oil, and de-icer air might require some sort of interrelated thermal processing or in a ship having varied thermal requirements for its evaporators, space heating, engine oil, and possibly a variety of electronic mechanisms demanding a special temperature environment. Such problems are usually quite lengthy and can become very confusing if a number of arrangements are to be analyzed. Both speed and clarity result when a graphical approach is used, involving the so-called operating-line, equilibrium-line analysis. This method, in turn, is rapidly worked using a simple and readily constructed device, similar to a protractor, which will be described in this paper.

THE OPERATING-LINE METHOD

The graphical method of heat exchanger design extensively developed by Kays and London [1] requires the use of the so-called Effectiveness-NTU method, which is now well covered by most modern heat transfer texts [2], [3], [4]. To analyze a heat exchanger graphically, we simply plot the temperature of the hot fluid (s) along the ordinate and the temperature of the cold fluid (s) along the abcissa. The *equilibrium line* is simply the line at 45 degrees specified by the equation, $T_h = T_c$, As noted in Figure 2, no point within a heat exchanger can lie underneath this equilibrium line since such a construction would imply a hot fluid colder than a cold fluid. From the First Law of Thermodynamics,

$$C_h(T_{h,\,in} - T_{h,\,out}) = C_c(T_{c,\,out} - T_{c,\,in}) \quad \ldots\ldots (1)$$

where the C's stand for *capacity rates* equal to the mass flow of a fluid times its specific heat. We define the *operating line* of a heat exchanger as the straight line on the diagram connecting the point defined by (T_h, T_c) at one end of the unit and (T_h', T_c') at the other end of the unit. For a counter-flow unit, the two pairs of temperatures are ($T_{h,\,in} - T_{c,\,out}$) and ($T_{h,\,out} - T_{c,\,in}$) as shown on Figure 2. The slope of such a line is $\Delta T_h / \Delta T_c$ which, from Equation 1, is equal to C_c/C_h, the *capacity rate ratio*. The *effectiveness* of a heat exchanger is defined as

$$\varepsilon = \frac{C_c(T_{c,\,out} - T_{c,\,in})}{C_{min}(T_{h,\,in} - T_{c,\,in})} = \frac{C_h(T_{h,\,in} - T_{h,\,out})}{C_{min}(T_{h,\,in} - T_{c,\,in})} \quad \ldots\ldots (2)$$

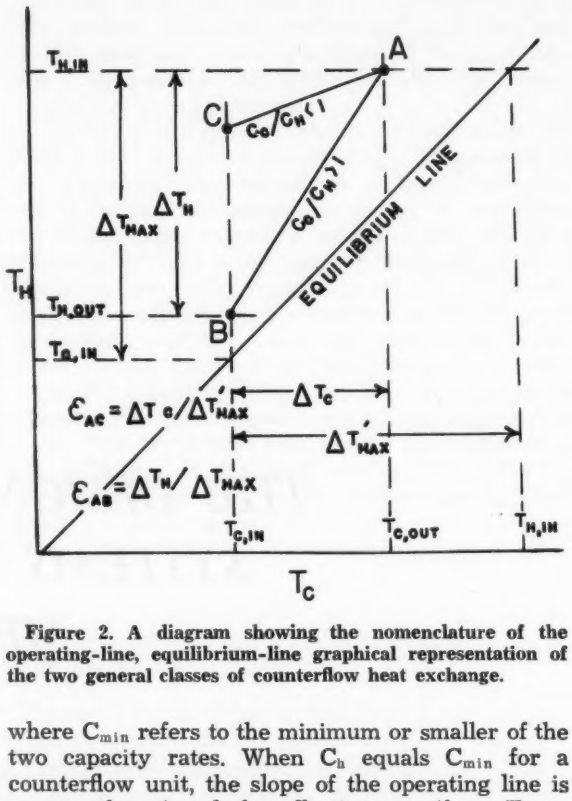


Figure 2. A diagram showing the nomenclature of the operating-line, equilibrium-line graphical representation of the two general classes of counterflow heat exchange.

where C_{min} refers to the minimum or smaller of the two capacity rates. When C_h equals C_{min} for a counterflow unit, the slope of the operating line is greater than 1 and the effectiveness (from Equation 2) is equal to the temperature change of the hot fluid divided by the hot temperature-in minus the cold temperature-in. This denominator can be represented by a vertical distance (ΔT_{max}) as shown in Figure 2. Note that the $T_{c,\,in}$ temperatures can be "transferred" to the hot axis by use of the equilibrium line. Thus the ratio of these two lengths on the plot, ΔT_h and ΔT_{max}, represents the effectiveness for this case. When C_c is C_{min}, we represent the effectiveness as the ratio of two lengths in a horizontal sense as shown in Figure 2. Examination of the noted references will show that parallel flow can also be easily sketched, and has an operating line with the negative slope.

MECHANICAL DETERMINATION OF THE VARIABLES

The operating line graph represents Equation 2. For a single unit, we would not usually bother with a graphic approach, but when several units are interconnected, this becomes worthwhile. Indeed, in the so-called indirect coupled systems [5], analysis without the help of a diagram is often formidable. In a given problem we may know the position (temperatures) of one point on the operating line, plus its slope (capacity rate ratio), and wish to find the effectiveness. Or we may know the unit effectiveness and one or more temperatures and wish to compute the capacity rate ratio. Or we may be

given the effectiveness and capacity rate ratio and need one or more temperatures. Whatever the problem, the simple mechanical computer in Figure 3 will make the task easier, particularly if repeated trials are to be undertaken as is so often the case in an optimization study. Further, the computer may prevent some of the errors that can result when the minimum becomes the maximum fluid during a series of computations having changing inputs.

The computer solves the equation,

$$\varepsilon = \Delta T / \Delta T_{max} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

It is most easily constructed from a transparent plastic right triangle having 45 degree corners. The inside is cut out as far as practicable and a movable arm pivoted as shown. When the arm lies along the equilibrium line, it crosses the ε-scale at the 100 per cent point. When the moveable arm lies at 45 degrees to the operating line, it crosses the ε-scale at 0 per cent. The ε scale is linear between 0 and 100 per cent.

The triangular portion of the computer can be used to insure that slope errors are not present. With the apparatus oriented as in Figure 4, move the pivot point to the upper end of the operating line. If the operating line lies *below* the 45 degree edge of the apparatus (line B in Figure 4) then C_c/C_h is greater than 1, C_h is the minimum and we should work with distances in a vertical direction, along the hot temperature axis. This is the case shown in Figure 3. If, however, the operating line lies *above* the 45 degree edge (line A in Figure 4) then the computer is incorrectly aligned for the problem at hand. It should be turned over and rotated so that the distances ΔT and ΔT_{max} refer to the cold temperature axis. This quick check should be made after or before each graphical calculation, depending on whether the line is known or not.

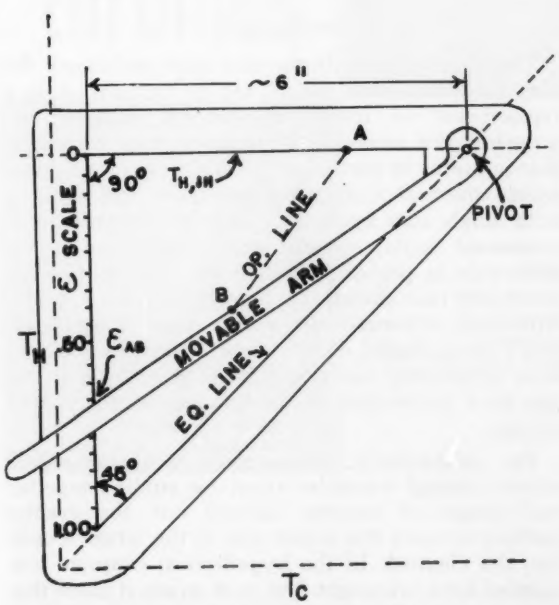


Figure 3. This sketch shows the construction details of the simple effectiveness computer (solid lines) and also indicates how it would compute C for a heat exchanger having an operating line as shown by the dotted lines.

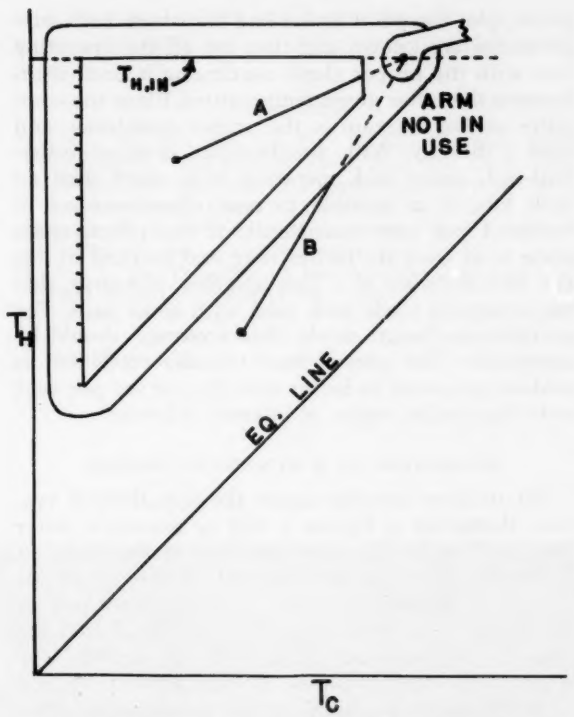


Figure 4. The simple computer is here placed so as to detect the magnitude of the slope of operating lines in relation to unity. (A slope less than, B slope more than one.)

Parallel flow can also be analyzed using this device, but is seldom encountered in practical design work.

Several types of problems can be quickly worked using the computer and a sheet of graph paper. For example: Given: $T_{c,\,in}$, $T_{h,\,in}$, ε, and C_c/C_h. Solution: first decide whether to work along the hot or cold axis by noting the value of the slope. Then align the horizontal edge in Figure 3 with either $T_{h,\,in}$ or $T_{c,\,in}$ lines and slanted edge with the equilibrium line. Move the arm to the known ε and mark on paper where the arm edge intersects the other known temperature. Erect a line on this point with a slope of C_c/C_h to the first temperature. This latter construction is rapidly done with a small protractor calibrated in slopes instead of degrees.

As a second example: Given: hot and cold temperatures at one end, the capacity rate ratio, and one temperature at the other end. Solution: on the

graph, plot the point at the end for which both temperatures are known and then lay off the operating line with the proper slope, continuing it until it intersects the other given temperature. Place the computer on the diagram in the proper orientation and read ε directly. With standard ten division-to-the-half-inch paper and operating lines more than an inch long it is possible to read effectivenesses to within 1 per cent consistently if the effectiveness scale is at least six inches long and marked at 2½ per cent divisions of ε. This assumes, of course, that the device is made and used with some care. For preliminary design work, this accuracy should be acceptable. The overall heat transfer coefficient is seldom estimated to better than five or ten per cent until the design region of interest is located.

APPLICATION TO A NUMERICAL PROBLEM

Let us now consider again the hypothetical system illustrated in Figure 1. Let us assume a water flow of 3000 lbs/hr, a specific heat of the water of 1 Btu/lb, F and a specific heat of the air of .24 Btu/lb, F. Then in unit No. 1 the capacity rate of the water, C_h is 3000×1 or 3000 Btu/hr, F and the capacity rate of the air, C_c is 6000×.24 or 1440. The slope of the operating line is 1440/3000 or .48 and C_c is the minimum fluid. On our graph paper (Figure 5) plot the point ($T_{h,\,in}$, $T_{c,\,out}$) for unit No. 1 which is (300 F, 250 F) as shown in the system diagram, Figure 1. A line with a slope of .48 is now drawn from this point to the known cold water temperature into unit No. 1 which is 120 F, and the operating line is established graphically. Now the computer is placed on the graph so that lengths along the horizontal are compared, since C_c is the minimum capacity rate. If the apparatus is placed on the diagram as shown in Figure 4, it will be seen that the operating line lies above the 45 degree line of the computer warning us that we must turn it over and rotate it to obtain ε. The calculated $T_{h,\,in}$ is, from Equation 1, 237.6 F and the effectiveness from Equation 2 is .722. With a computer as described in the previous section and an operating line 2½ or more inches long an ε of .72 is easily read. With effectiveness, overall heat transfer coefficient, and the flow arrangement known, an appropriate chart linking the capacity rate ratio, the number of transfer units and ε can be consulted, and the necessary heat transfer area and unit volume computed. Details of this type of calculation are easily found in the noted references. Notice that we are working here with a cross-flow rather than a counterflow unit. This is possible in multiple unit systems when we know, as we do here, whether the overall arrangement is counterflow or parallel flow.

Unit No. 2 can be worked out in the same way, noting that the capacity rate and slope is now 2160/3000 or .72 since this unit has an increased air flow through it. Finally, unit No. 3 can be graphed as shown in Figure 5 and the effectiveness of this

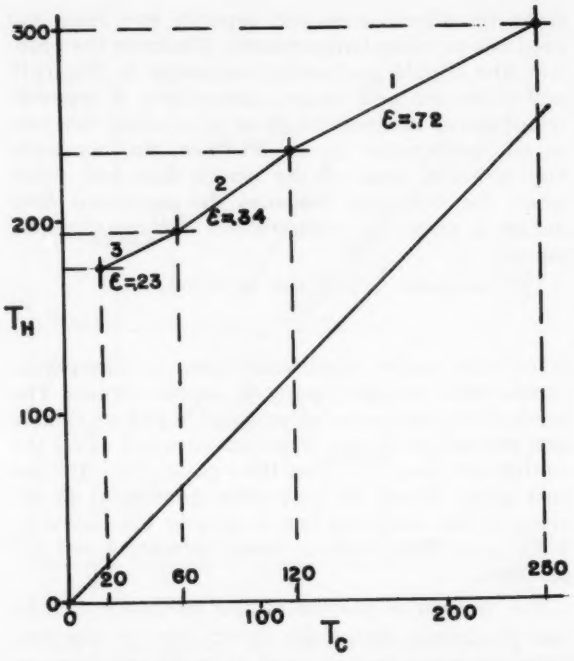


Figure 5. The completed graphical solution of the system diagrammed in Figure 1.

unit obtained. The overall computation is easily checked for accuracy using Equation 1 applied to the three units taken together, being careful to include the energy sent into the air in unit No. 2.

DISCUSSION

The method of multiple unit heat exchanger design described here should not be thought of as a replacement of more conventional analytic approaches, but rather as a supplementary technique that is useful in certain situations. For the engineer whose thermal system computations deal entirely with single unit systems or only infrequently with connected units, straight computation using the slide rule is probably best. Even here though, an operating line sketch may clarify certain complex situations. Alternatively, a full dress optimization study using digital computing machinery cannot be done graphically nor would the inherent one or two per cent inaccuracy be acceptable in many such studies.

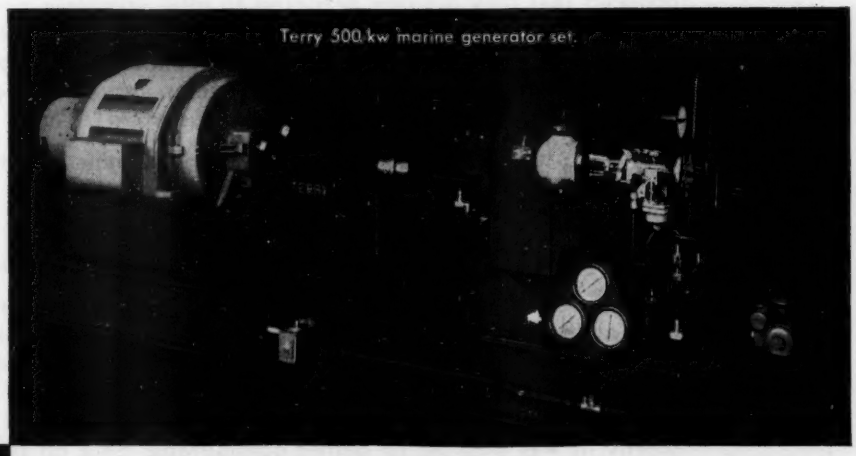
For preliminary, exploratory work, however, where several variables must be studied together and ranges of interest blocked out, the graphic method is much the fastest and in the writer's opinion, the clearest. In the hypothetical example considered here, we might first wish to see if more than a single cross-flow unit should lie on either side of the unit carrying the two air flows, and whether the two air flows should be handled in separate units. The hot water flow would probably be varied over

several values, and both air flows would have, no doubt, a design range, rather than a single set flow. Farther, we might wish to investigate the stability of the system by introducing an "upset" or temperature excursion in one of the fluid streams and see how this affected the load on the reactor and the other parameters. All such computations are easily done using graph paper and the mechanical computer. An engineer might spend one or two days on such preliminary number-manipulation, too little time to justify a large formal programming effort, yet enough to make clarification and simplification of the methods worth while. It would seem that the system of several interconnected heat exchangers will become a larger and larger problem for engineers working in nuclear, solar, and similar modern areas.

REFERENCES

[1] Kays, W. M. and London, A. L., "Compact Heat Exchangers," The National Press, Palo Alto, Calif., 1955.
[2] Schenck, H., "Heat Transfer Engineering," Prentice Hall, Inc., Englewood Cliffs, N.J., 1959.
[3] Giedt, W. H., "Principles of Engineering Heat Transfer," D. Van Nostrand, Inc., Princeton, N.J., 1957.
[4] Krieth, E., "Principles of Heat Transfer," International Text Book Co., Scranton, Pa., 1958.
[5] London, A. L. and Kays, W. M., "The Liquid-Coupled Indirect-Transfer Regenerator For Gas Turbine Plants," ASME Preprint, No. 80-A-89, 1951.

Terry steam turbines


Terry 500 kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

THE TERRY STEAM TURBINE CO.
TERRY SQUARE, HARTFORD 1, CONN.

TT-1211

HIGHER STEAM CONDITIONS FOR MARINE TURBINES

At present, the most widely accepted steam conditions for marine turbines is about 600 lb./sq. in. gauge at 850 deg. F. Fifteen years ago these conditions would have been about 400 lb./sq. in. gauge at 750 deg. F. The difference between thse two levels has made possible savings in fuel consumption of from 4 to 5 per cent when using modern installations. A recent statement by the International General Electric Company, New York, recommends that the next major upward step should be to at least 850 lb./sq. in. gauge at 950 deg. F. This recommendation is based upon extensive studies of existing turbines, both land-based and in ships of the United States Navy, which successfully employ steam conditions in excess of those now recommended. With steam conditions at the new level, the company anticipate fuel saving of between 5 and 7 per cent over the former accepted level. For instance, for a single-screw propulsion plant rated at about 25,000 s.h.p., it is claimed that an all-purpose fuel rate of less than 0.465 lb./s.h.p./hr. can be obtained. The company have announced that they are now prepared to offer complete marine steam innounced that they are now prepared to offer complete marine steam installations for opration at the advanced steam conditions and are prepared to quarantee the fuel rate. Assistance will be provided, if required, in the design and arrangement of those items, such as piping, valves, etc., which are not supplied as part of the "packaged" plant.

The Shipbuilder and Marine Engine-Builder, March 1961

BIOLOGICAL FOULING AND HULL CORROSION

At the seventh meeting of a group of experts from 13 member countries of the Organization for European Economic Co-operation, on the biological fouling and corrosion of ships' hulls, it was announced that a report on the biological and hydrological characteristics of the European testing stations participating in the group's program will be published shortly. It was possible to gather considerable data on the rafts in use, the hydrological conditions of the water and the nature of the fouling encountered. This information is not limited to Europe alone, as data has been received recently from the United States of America and the British Commonwalth; the second part of this report, which is to appear at the end of the year, will deal with these extra-European testing stations.

Furthermore, an international catalog with colored photographs and descriptions of the main marine fouling organisms found on ships coming into European ports is at present being prepared for publication.

The meeting, held in France, discussed the work of the different subcommissions of the group engaged in detailed studies of biology and ecology of fouling organisms, standardization of testing methods, fundamental research, and corrosion of the underwater surface of ships' bottoms related to fouling. It was decided that further studies should be undertaken to unify rafts for comparative tests of biological fouling and that tests should be continued until 1963 to obtain comparative data with the testing stations of Spain, Portugal and the United States of America —countries which only recently joined the work of the group. In the field of fundamental research it was proposed to study the reaction of the different species of fouling organisms to toxins.

The Shipbuilder and Marine Engine-Builder, July 1961

R. KAUFMAN and A. SEGALO

ESTIMATING STEAM REQUIREMENTS (IN POUNDS) TO RAISE PRESSURE IN A PRESSURE VESSEL

THE AUTHORS

R. E. Kaufman, supervisory marine engineer, has been with the Naval Boiler and Turbine Laboratory for 25 years. He is in charge of Machinery Branches Special Projects Group having cognizance of gear tooth material evaluations, lubrication system component evaluation and development, catapult receiver system controls evaluations, etc.

A. Segalo, engineering aide, has been with the Naval Boiler and Turbine Laboratory for twenty-one years except when interrupted by World War II years. He was a Master Sergeant in the army and was in the Battle of the Bulge. At the laboratory he has been in the Machinery Branches Special Projects Group and has been concerned with evaluation studies of gear tooth surface materials and lubricating system components.

THERE ARE A number of occasions where it is desirable to estimate the amount of steam in pounds that it takes to raise the pressure in a pressure-vessel a definite amount. The enclosed type table was very useful at the Naval Boiler and Turbine Laboratory in calculating catapult receiver steam quantities. It is thought that this can be applied to other type pressure vessels. A number of simplifying assumptions have to be made which aren't strictly true but which enable an estimate which isn't in error more than several per cent. It has to be assumed that a throttling action takes place with no work or heat passed out of the system, i.e., a constant enthalpy expansion

The operation of the table is thus:

Divide pressure-vessel volume in cu. ft. by 1000, then multiply this by coefficient (see table). This will give the factor for steam weight increase for one psi pressure increase. Multiply factor by number of psi increase to fill vessel. This will give steam increase in pounds to raise the pressure the specified amount.

To determine coefficient, first select the table in which the Pressure Before Throttling Point most nearly resembles the actual situation. Enter this table with the temperature before the throttling point and the pressure in the vessel.

FACTOR TO CONVERT PRESSURE-VESSEL PRESSURE INCREASE TO STEAM WEIGHT INCREASE

Constant Enthalpy Expansion from Specified Pressure Before Throttling Point

Pressure Before Throttling Point 1200 psi

$\left(\frac{\text{Pressure Vessel Vol.}}{1000}\right)$ (Coeff.)=Factor

(Factor) (psi Increase)=lbs. of Steam Increase

Pressure-Vessel—Pressures (psia)	Coeff. 580	600	620	640	660	680	700
1100	2.24	2.10	2.00	1.91	1.84	1.78	1.72
1000	2.23	2.10	2.00	1.92	1.84	1.77	1.77
900	2.22	2.09	2.00	1.91	1.84	1.77	1.71
800	2.21	2.10	1.99	1.91	1.83	1.77	1.71
700		2.08	1.98	1.90	1.83	1.76	1.71
600		2.08	1.98	1.89	1.82	1.76	1.70
500		2.07	1.97	1.89	1.82	1.75	1.70
400		2.06	1.97	1.88	1.81	1.75	1.69
300		2.06	1.96	1.88	1.81	1.74	1.69
200		2.05	1.95	1.87	1.80	1.74	1.68
100		2.05	1.95	1.86	1.79	1.73	1.67

Temp. Before Throttling Pt.

Pressure Before Throttling Point 1100 psi

$\left(\frac{\text{Pressure Vessel Vol.}}{1000}\right)$ (Coeff.)=Factor

(Factor) (psi Increase)=lbs. of Steam Increase

Pressure-Vessel—Pressures (psia)	Coeff. 580	600	620	640	660	680	700
1000	2.14	1.03	1.95	1.87	1.80	1.74	1.69
900	2.13	1.03	1.94	1.86	1.80	1.74	1.69
800	2.13	2.02	1.93	1.86	1.79	1.73	1.68
700	2.12	2.02	1.93	1.86	1.79	1.73	1.68
600	2.12	2.01	1.92	1.85	1.79	1.73	1.67
500	2.11	2.00	1.92	1.84	1.78	1.72	1.67
400	2.10	2.00	1.91	1.84	1.77	1.72	1.67
300	2.09	1.99	1.91	1.83	1.77	1.71	1.66
200	2.09	1.98	1.90	1.83	1.76	1.71	1.66
100	2.09	1.98	1.90	1.82	1.76	1.70	1.65

Temp. Before Throttling Pt.

Pressure Before Throttling Point 1000 psi

$\left(\frac{\text{Pressure Vessel Vol.}}{1000}\right)$ (Coeff.)=Factor

(Factor) (psi Increase)=lbs. of Steam Increase

Pressure-Vessel—Pressures (psia)	Coeff. 580	600	620	640	660	680	700
900	2.06	1.97	1.89	1.83	1.77	1.71	1.66
800	2.06	1.96	1.89	1.82	1.76	1.71	1.66
700	2.05	1.96	1.88	1.82	1.76	1.70	1.66
600	2.04	1.95	1.88	1.81	1.75	1.70	1.65
500	2.03	1.95	1.87	1.81	1.75	1.69	1.65
400	2.03	1.94	1.87	1.80	1.74	1.69	1.64
300	2.02	1.94	1.86	1.79	1.74	1.69	1.64
200	2.02	1.93	1.86	1.79	1.73	1.68	1.63
100	2.02	1.93	1.85	1.78	1.72	1.67	1.63

Temp. Before Throttling Pt.

Pressure Before Throttling Point 900 psi

$\left(\frac{\text{Pressure Vessel Vol.}}{1000}\right)$ (Coeff.)=Factor

(Factor) (psi Increase)=lbs. of Steam Increase

Pressure-Vessel—Pressures (psia)	Coeff. 580	600	620	640	660	680	700
800	1.99	1.91	1.84	1.79	1.73	1.68	1.63
700	1.98	1.91	1.84	1.78	1.72	1.68	1.63
600	1.98	1.90	1.84	1.78	1.72	1.67	1.63
500	1.98	1.90	1.83	1.77	1.72	1.67	1.62
400	1.97	1.89	1.83	1.77	1.71	1.67	1.62
300	1.96	1.89	1.82	1.76	1.71	1.66	1.61
200	1.96	1.88	1.81	1.76	1.70	1.66	1.61
100	1.95	1.88	1.81	1.75	1.70	1.65	1.60

Temp. Before Throttling Pt.

"SOCIETY OF AEROSPACE MATERIAL AND PROCESS ENGINEERS"

REINFORCED PLASTICS FOR HYDROSPACE VEHICLES

ACKNOWLEDGMENT

This article is reprinted from a paper presented to the Filament Winding Conference of The Society of Aerospace Material and Process Engineers, March 28, 29, and 30, 1961. The authors are J. E. Buhls, Jr. and J. G. Pulos of the Structural Mechanics Laboratory, David Taylor Model Basin and W. R. Graner of the Bureau of Ships.

BACKGROUND

THE GREAT OCEANS cover 70 per cent of the earth's surface, as shown in Figure 1, and 70 per cent of these oceans lie between 10,000 and 20,000 ft. in depth. Hence, in man's quest to explore, utilize, and to better understand the seas around him, he must develop high-strength hull structures which can withstand these deep-submergence pressures and still be sufficiently light in weight to carry a practical payload of crew and equipment.

The ideal characteristics for metals, which may be extended to apply to any material, for pressure-hull application have been summarized and discussed at some length by Owen and Sorkin. [1] These characteristics are shown in Table 1.

By virtue of their density, strength, and modulus, glass-reinforced plastics appear to have great promise as a structural material for deep-diving submersibles. Furthermore, reinforced plastics can be tailor-made to have high strength in preferred directions so that in this case isotropy is no longer a desirable characteristic. Other favorable properties of these nonmetallics are their availability, formability, and nonmagnetic characteristics.

TABLE 1

Ideal Characteristics of Materials for Hydrospace Vehicles

Density—As low as magnesium (0.065 lbs/cu in.).
Yield Strength—300,000 psi.
Moduli—Tension 40×10^6 psi, shear 15×10^6 psi.
Toughness—Will not fracture in a brittle manner under severe plastic deformation at 0 deg F or lower.
Weldability—95-percent joint efficiency or greater in as welded condition for yield strength, toughness and fatigue strength.
Formability—Hot formed or cold formed to shape without the necessity for subsequent heat treatment.
Repairability—Weld repairable under service conditions.
Fatigue—Notched fatigue strength of welded structure at least 90 per cent of unnotched fatigue strength of basic material for low-cycle, high stress and plastic strain conditions wherein number of peak stress cycles is 20,000 or less.
Corrosion—Not susceptible to stress corrosion. Corrosion-fatigue strength equal to air-fatigue strength.
Stability—Will not creep or change dimensions significantly under operating stress (75 per cent of yield strength).
Isotropy—Mechanical properties identical in any plane.

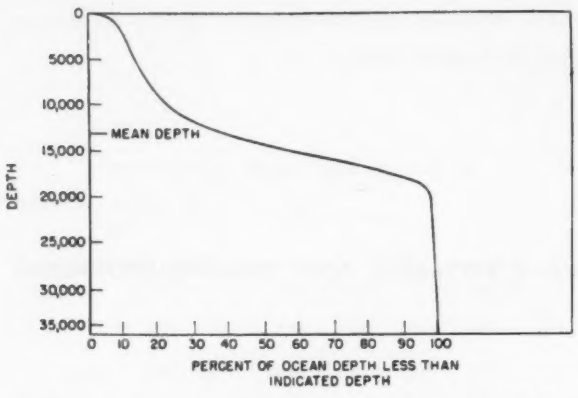


Figure 1. Percentage Distribution of the Depth of the Ocean.

Possible creep under long-term hydrostatic pressure, strength reductions due to cyclic fatigue, and aging are potentially serious shortcomings. There is also a problem with regard to achieving high-strength repairs. The magnitude of these shortcomings can only be established after extensive investigations.

A survey of the literature showed that there was very little information on the design of shell structures of composite materials, such as GRP, to withstand high *external* hydrostatic pressures. Indeed, most work has involved comparatively thin-walled containers for internal pressure application. In the areas of interest to the pressure hull designer, information is virtually nonexistent. Barnet and Lloyd [2] have reported on tests of small-diameter GRP cylindrical and hemispherical shells, some made of glass fabric and others of glass-roving type of reinforcement, which were subjected to moderate submergence pressures. Results of these tests did indicate that significant reductions in the allowable design stress were necessary for satisfactory performance under continuous immersion for periods up to one year. However, it appears fair to state that the materials available at this time are more efficient structurally than earlier materials.

The apparent advantage of using glass-reinforced plastics as the material for cylindrical pressure hulls can be seen in Figure 2 for unstiffened cylinders and in Figure 3 for ring-stiffened cylinders. The curves show the predicted strength-weight characteristics for cylindrical shells of various materials loaded by external hydrostatic pressure. In the construction of the figures the same formulas were used for all materials. These formulas have been proven valid for metals but not, as yet, for anisotropic materials such as reinforced plastics. The extensive calculations required were carried out with the aid of the Model Basin's IBM-704 computer.

The physical properties used in the calculations represent the best materials available today as well as those expected to be available in the near future. It was assumed that the properties were the same in both the circumferential and longitudinal directions.

For the glass-reinforced plastics, various combinations of density, strength, and modulus were assumed. The first combination represented values similar to those of materials available in 1959, i.e., a density of 0.07 lb/cu in., a strength of 70,000 psi, and a Young's modulus of 4.8×10^6 psi. The other combinations of properties for the plastics reflect material properties expected from higher glass content and the use of glass fibers with higher strength and modulus.

The physical properties of the metals used in obtaining the curves of Figures 2 and 3 include HY-100 (100,000-psi yield strength) steel and the higher strength and lighter weight alloys that could be available in the next few years, i.e., HY-150 and HY-200 steels. 60,000-psi aluminum and beryllium, and 150,000-psi titanium.

Where the yield strength of the material shown in Figure 2 is less than that shown in Figure 3, the modulus of elasticity, as reflected in the buckling pressure, is the controlling factor, and no advantage can be gained by increasing the yield strength. The curve for steel in Figure 2 is a good example of this. In order to have an unstiffened steel cylinder fail by elastic shell buckling over the weight-displacement range considered, it is only necessary to have the yield strength of the steel exceed 36,000 psi.

Beryllium is the only material where failure of an unstiffened cylinder occurs by yielding of the shell over a significant portion of the weight range considered in Figure 2.

The material densities used in computing the weights of the metal cylinders were 0.283 lb/cu in. for steel, 0.160 lb/cu in. for titanium, 0.100 lb/cu in. for aluminum, and 0.0658 lb/cu in. for beryllium.

In Figure 2, for unstiffened cylinders, the nonlinear portion of each curve represents the elastic shell buckling mode of failure. The straight-line of each curve in Figure 2 represents the pressure at which the stresses reach the strength of the material. For the metal cylinders, failure was assumed to occur when the biaxial "effective stress" determined from the Hencky-Huber-Von Mises theory of failure reached the yield strength of the material. The circumferential and longitudinal membrane stresses, $\delta_c=\frac{pR}{h}$ and $\delta_L=\frac{pR}{2h}$, respectively, were used in these calculations. For the reinforced plastics, failure was assumed to occur when the circumferential membrane stress δ_c reached the fracture stress of the material. This latter assumption may be conservative, but it was deemed necessary because of the lack of data on the response of GRP

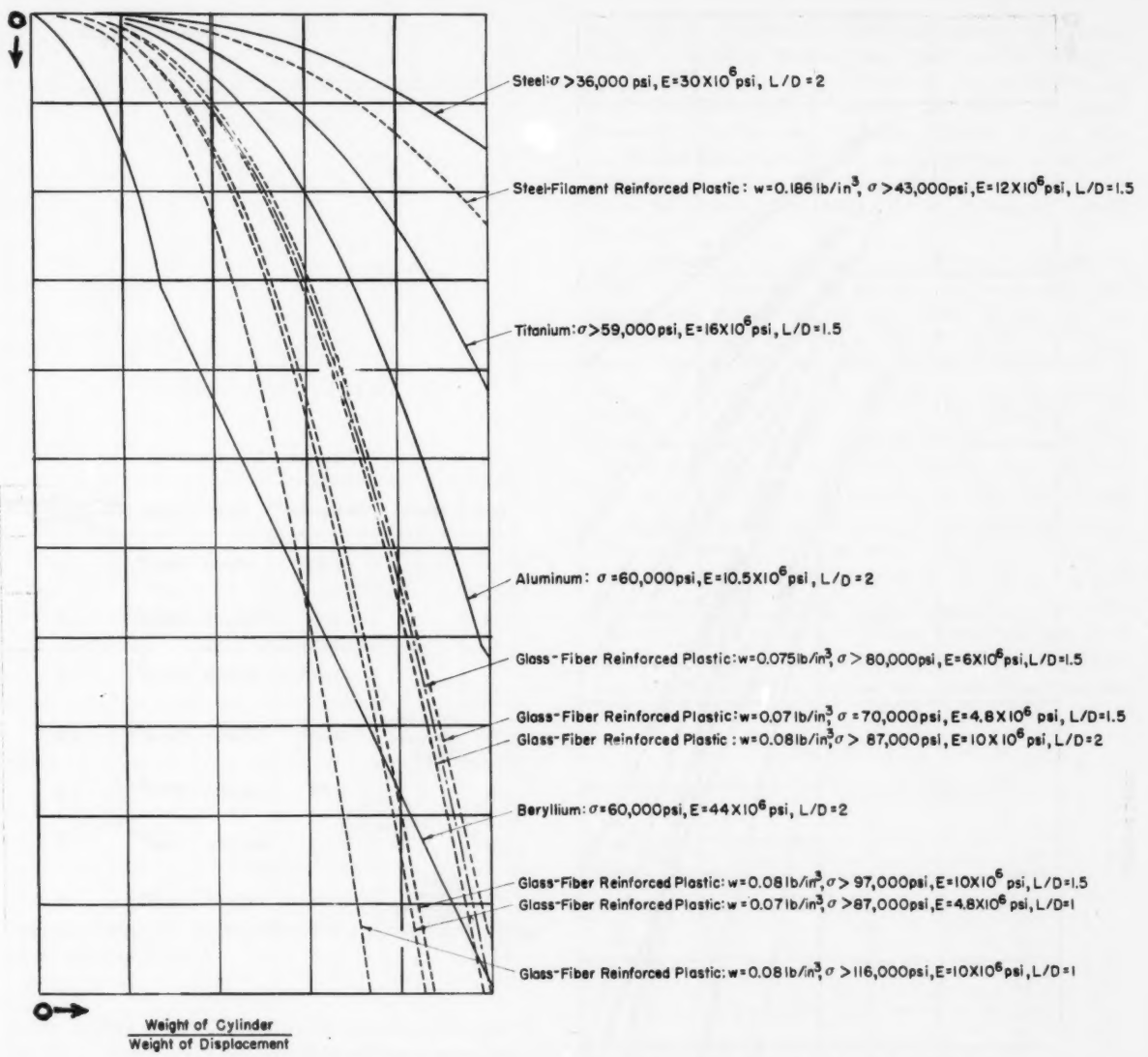
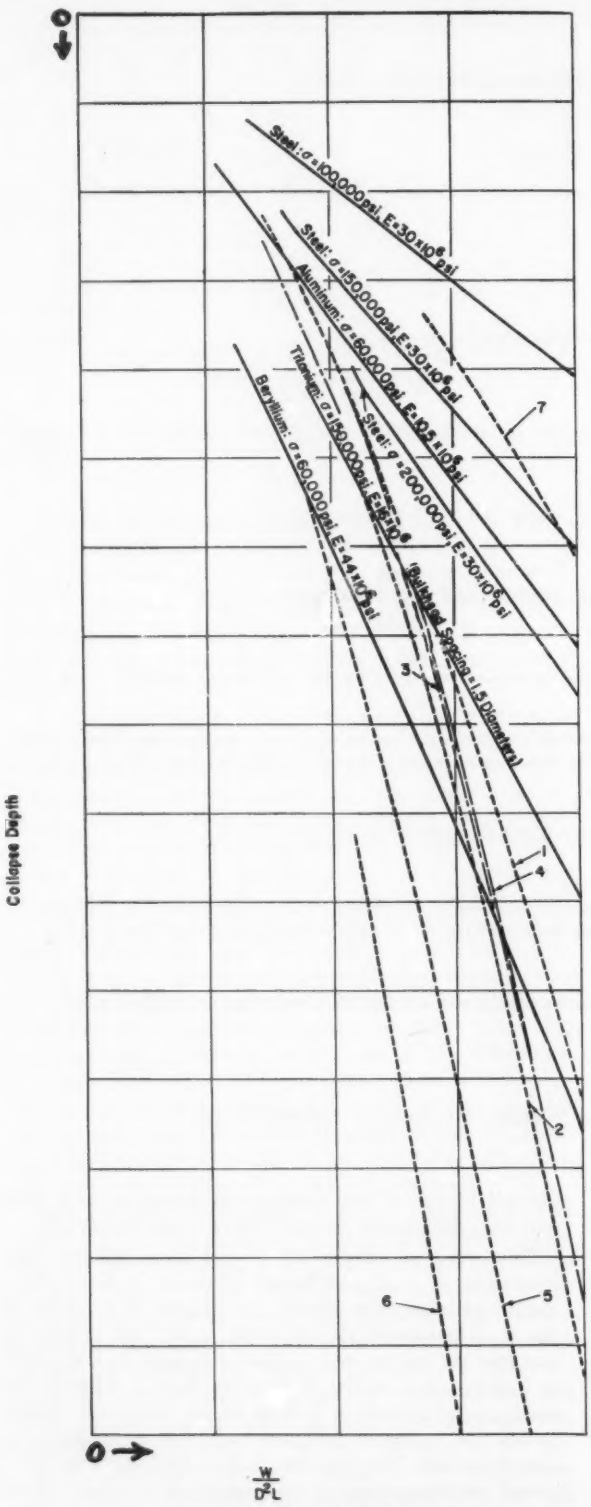

Steel: σ > 36,000 psi, E = 30 X 10^6 psi, L/D = 2
Steel-Filament Reinforced Plastic: w = 0.186 lb/in^3, σ > 43,000 psi, E = 12 X 10^6 psi, L/D = 1.5
Titanium: σ > 59,000 psi, E = 16 X 10^6 psi, L/D = 1.5
Aluminum: σ = 60,000 psi, E = 10.5 X 10^6 psi, L/D = 2
Glass-Fiber Reinforced Plastic: w = 0.075 lb/in^3, σ > 80,000 psi, E = 6 X 10^6 psi, L/D = 1.5
Glass-Fiber Reinforced Plastic: w = 0.07 lb/in^3, σ = 70,000 psi, E = 4.8 X 10^6 psi, L/D = 1.5
Glass-Fiber Reinforced Plastic: w = 0.08 lb/in^3, σ > 87,000 psi, E = 10 X 10^6 psi, L/D = 2
Beryllium: σ = 60,000 psi, E = 44 X 10^6 psi, L/D = 2
Glass-Fiber Reinforced Plastic: w = 0.08 lb/in^3, σ > 97,000 psi, E = 10 X 10^6 psi, L/D = 1.5
Glass-Fiber Reinforced Plastic: w = 0.07 lb/in^3, σ > 87,000 psi, E = 4.8 X 10^6 psi, L/D = 1
Glass-Fiber Reinforced Plastic: w = 0.08 lb/in^3, σ > 116,000 psi, E = 10 X 10^6 psi, L/D = 1
Weight of Cylinder / Weight of Displacement

Figure 2. Strength-Weight Characteristics of Unstiffened Cylindrical Pressure Vessels.

materials when subjected to high compressive stresses, particularly biaxial compressive stresses resulting from hydrostatic pressure.

The curves in Figure 3 show the results of calculations for which it was assumed that the metal cylinders had T-frames and the reinforced plastic cylinders had rectangular frames. For a given material and weight-volume ratio, the most efficient or optimum design was selected. In other words, it was assumed that the frames failed, either by overall instability of the frame-shell combination or by yielding, at the same calculated pressure at which the shell failed by axisymmetric collapse. An accepted amount of out-of-roundness was assumed in calculating the bending stresses in the frames. The overall length of the cylinder assumed in each case was two diameters except where noted otherwise.

The various stages of progressive deformation occurring in a ring-stiffened cylinder under hydrostatic pressure are shown in Figure 4. Failure of the shell between frames of the metal cylinders was assumed to occur when plastic hinges had formed at midbay and at the frames so that a three-hinge mechanism, as shown in Figure 4d, occurred. Theory for this mode of collapse has been developed by Lunchick [3]. The failure of the shell for the reinforced plastic cylinders was assumed to occur when either the circumferential stress at midbay or the longitudinal stress at a frame reached the strength of the material; these critically stressed regions are



Fiberglass Characteristics

Curve	Material	Density, lb/in³	σ, psi	E, psi	Bulkhead Spacing / Diameter
1	Glass-Fiber Reinforced Plastic	0.07	70,000	4.8×10^6	1.5
2		0.07	100,000	4.8×10^6	1.0
3		0.075	90,000	6.0×10^6	1.5
4		0.08	100,000	10×10^6	2.0
5		0.08	150,000	10×10^6	1.5
6		0.08	200,000	10×10^6	1.0
7	Steel-Filament Reinforced Plastic	0.186	150,000	12×10^6	1.5

Figure 3. Strength-Weight Characteristics of Ring-Stiffened Cylindrical Pressure Vessels.

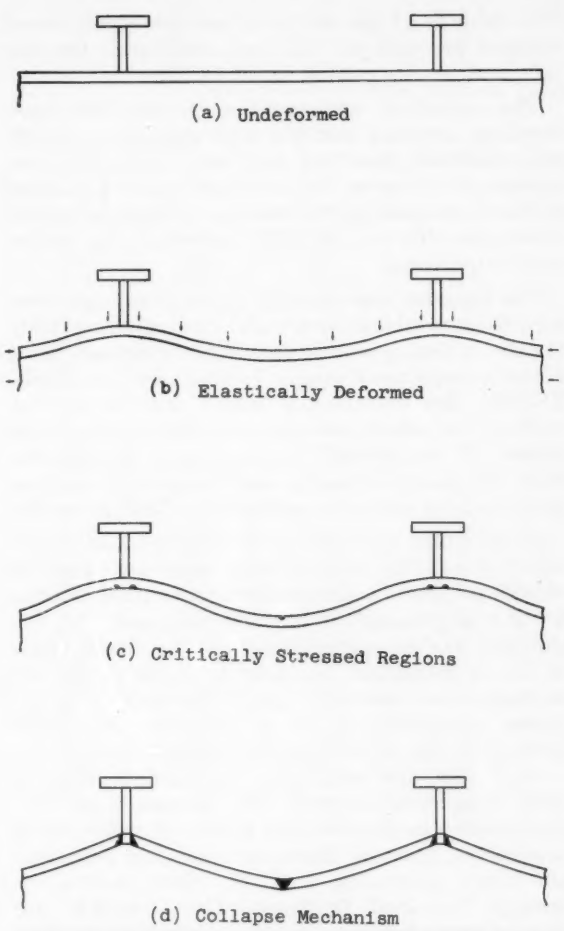


Figure 4. Mechanism of Failure for Ring-Stiffened Cylindrical Pressure Vessels.

shown in Figure 4c. The failure criterion for metals has been reasonably well confirmed by experiment, but the one for plastics has not, although it is probably conservative.

For the reasons indicated in Figures 2 and 3 the Navy, in searching for materials for submersible hulls, became interested in glass-reinforced plastics.

DAVID TAYLOR MODEL BASIN TESTS AND RESULTS

It is appropriate at this time to trace some history pertinent to the development of current interest within the U.S. Navy in studying the feasibility of composite materials such as GRP for naval structures application.

In April 1959 the Zenith Plastics Company of Gardena, California, a division of Minnesota Mining and Manufacturing Company, proposed to the Office of Naval Research the possible application of plastic materials developed by the parent company to a variety of plate and shell structures of interest to the U.S. Navy. Subsequent conferences arranged by the Office of Naval Research and attended by cognizant personnel of Zenith, the Office of Naval Research, the Bureau of Ships, and the David Taylor Model Basin led to the establishment of a joint program of exploratory research to study the feasibility of using such materials in cylindrical shell structures.

A relatively large-size unstiffened cylindrical shell was fabricated by Zenith, at their own expense, and forwarded to the Model Basin for instrumentation and testing. The test cylinder, designated Model ZP-3562, had an inside diameter of 31.06 in., a wall thickness of 1.61 in., and an overall length of 59.0 in. The ends of the cylinder were closed by heavy steel plates machined to fit the inside of the cylinder and held together by a tie rod. The end closure plates reduced the effective length of the test section to 55.0 in. A schematic diagram of the cylinder in the test tank is shown in Figure 5.

The cylinder was fabricated by winding a glass-fiber, reinforced epoxy resin tape on a mandrel. The shell wall consisted of two layers of tape with the glass fibers in the circumferential direction and one layer of sheets having the glass fibers in the

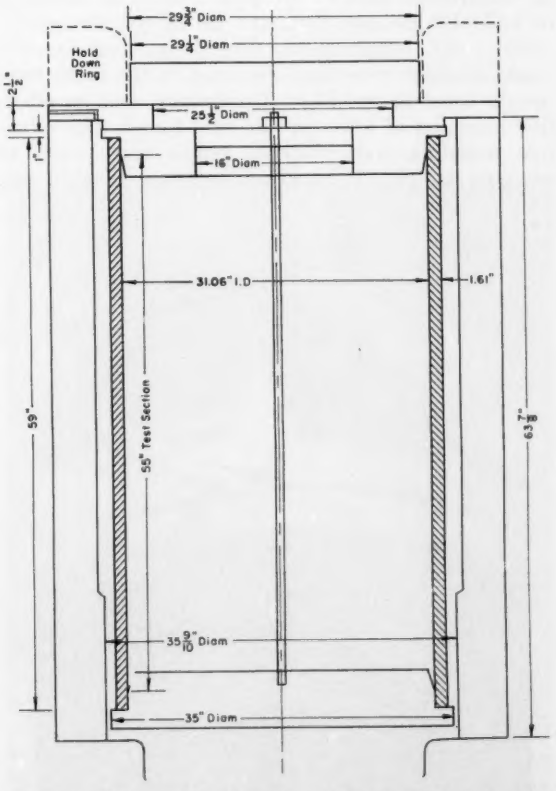


Figure 5. Schematic Diagram of Model ZP-3562 in Test Tank.

longitudinal direction. This buildup was repeated until the required thickness was obtained.

Nominal mechanical properties of the cured material used in the test cylinder were furnished by the manufacturer to be as follows:

Density γ, 0.070 lb/cu in.

Yield strength in the circumferential direction $\sigma_{y\phi}$, 70,000 psi

Modulus of elasticity in the circumferential direction E_ϕ, 4.8×10^6 psi

Poisson's ratio ν, 0.1

The cylinder was instrumented with two-element strain gage rosettes on the inside and outside surfaces of the shell at midlength and along one generator. The cylinder was loaded with external oil pressure to a maximum of 3000 psi. After completion of tests at the Model Basin the cylinder was loaded to failure, using water pressure, in the Naval Research Laboratory 4-ft diameter test tank.

Failure occurred at a pressure of 3735 psi after the cylinder had sustained 3750 psi for approximately 2 min. When failure occurred, the cylinder split along one generator with some circumferential tearing at midlength and considerable delamination in the wall thickness as shown in Figure 6.

The strain-sensitivity factors at midlength were used in conjunction with the membrane stresses for an unstiffened tube to compute moduli of elasticity of 4.85×10^6 psi and 3.44×10^6 psi in the circumferential and longitudinal directions, respectively. These moduli were then weighted in the same two-to-one ratio as the fiber distribution and an effective modulus of 4.38×10^6 psi was found. The effective modulus and effective length were used to compute an elastic buckling pressure of 3674 psi.

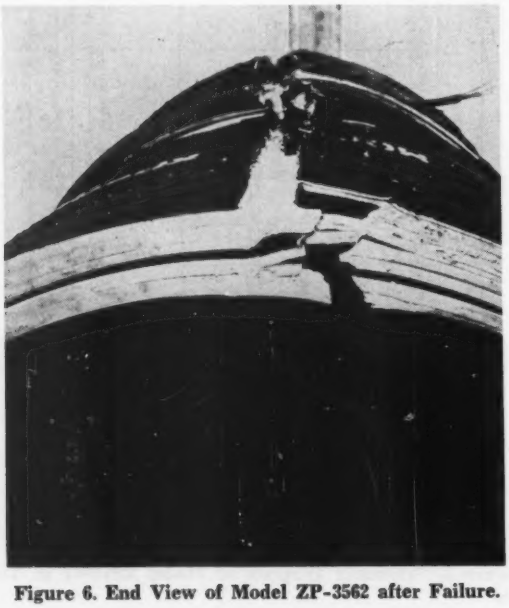


Figure 6. End View of Model ZP-3562 after Failure.

This value is 1.7 per cent less than the experimental collapse pressure of 3735 psi. Additional test details and results can be found in [4].

The excellent agreement with the computed buckling pressure and the high strength-to-weight ratio realized from this test were sufficiently encouraging to warrant the establishment of a planned research program by the Bureau of Ships to further investigate the use of GRP materials for underwater structures.

The program was established to investigate *commercially available* materials and winding techniques by testing simple unstiffened cylinders using a test arrangement similar to that used for Model ZP-3562. The testing of a limited number of ring-stiffened cylinders was also included in the initial phases of the program to investigate the applicability of design formulas and theoretical analyses developed for isotropic materials to GRP materials.

To minimize costs and to be able to utilize available test facilities with working pressures in excess of 3000 psi, small-scale models with an inside diameter of approximately 6 in. were designed. The unstiffened models contemplated for the initial phase of the investigation are listed in Table 2. The dimensions were selected to cover the range of thicknesses considered to be of interest. The letter prefixed to the model number indicates the manufacturer and the technique employed in winding these cylindrical models.* The B-models are filament-wound in five discreet layers, of which three have circumferential fibers and two have longitudinal fibers, producing a 3C:2L fiber distribution through the shell thickness. The G-models are filament-wound using complete dispersion of fibers resulting in a 2C:1L buildup. The H-models are also filament-wound but have a buildup of one circumferential layer and two layers helically wound at a 45-deg angle. The Z-models are wound of a glass-fiber reinforced epoxy-resin tape; each of these cylinders is built up in a sequence of two circumferential plys and one longitudinal ply repeated to produce a 2C:1L distribution of fibers completely dispersed through the thickness.

Six of the models listed in Table 2 have already been tested to collapse under short-term loading. Photographs of the models after failure are shown in Figures 7 through 12. All models were instrumented at midlength, on both the inside and outside surfaces with two-element strain rosettes. The same test procedure as for ZP-3562 was followed. The measured circumferential and longitudinal strains were used in conjunction with the membrane

* The cylinders were fabricated at the request of the Model Basin. The participating manufacturers were chosen on the basis of available information and inquiries, conducted at the request of the Bureau of Ships to establish willingness to participate in the program.

TABLE 2

Unstiffened Cylinder Models Planned for Glass-Reinforced Plastics Program

Model No.	Inside Diam. (in.)	Shell Thick (in.)	Length (in.)	Exper. Collapse Pressure (psi)	Material Density lb cu in.	Shell Lay-up	Test
B-1	5.987	0.319	11.47	5000	0.078	3C:2L	Short Term
B-2	5.986	0.320	22.40		0.078	3C:2L	
B-3	5.984	0.178	11.43	1225	0.0752	3C:2L	Short Term
B-4	5.983	0.309	11.46		0.0779	3C:2L	
B-5	5.977	0.384	11.46		0.0787	3C:2L	
B-6	5.982	0.457	11.28		0.0780	3C:2L	
G-1	6.	0.180	11.4			2C:1L	
G-2	6.	0.308	11.4			2C:1L	
G-3	6.	0.380	11.4			2C:1L	
G-4	6.	0.455	11.4			2C:1L	
H-1	5.940	0.197	11.40	910	0.0751	1C:2-45°	Short Term
H-2	5.943	0.172	11.41		0.0755	1C:2-45°	
H-3	5.938	0.325+	11.41			1C:2-45°	
H-4	5.936	0.318+	11.40			1C:2-45°	
H-5	5.938	0.382	11.40		0.0763	1C:2-45°	
H-6	5.937	0.381	11.42		0.0761	1C:2-45°	
H-7	5.937	0.450+	11.40			1C:2-45°	
H-8	5.938	0.455+	11.40			1C:2-45°	
Z-1	6.012	0.313	11.39	3550	0.068	2C:1L	Short Term
Z-2	6.012	0.313	11.39	3400	0.068	2C:1L	Creep
Z-3	5.994	0.373	11.40	7900	0.0781	2C:1L	Short Term
Z-4	5.997	0.380	11.40		0.0773	2C:1L	
Z-5	6.001	0.450	11.40		0.0754	2C:1L	
Z-6	5.998	0.449	11.40		0.0749	2C:1L	
Z-7	5.995	0.180	11.40	1325	0.0752	2C:1L	Short Term

Figure 7. Interior View of Model Z-1 after Failure.

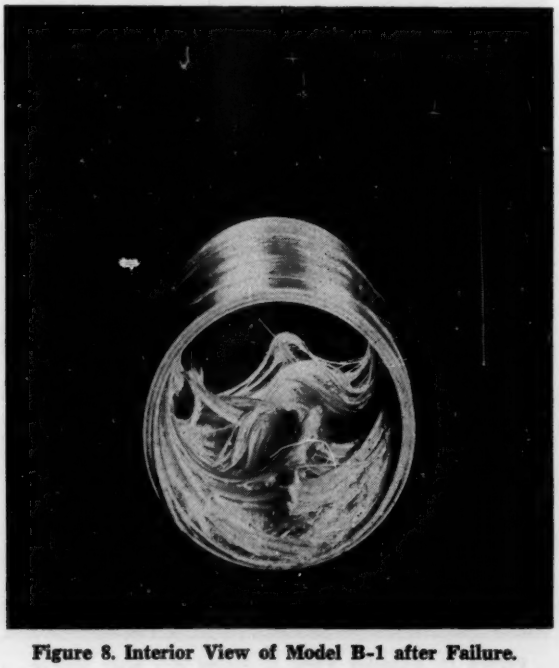


Figure 8. Interior View of Model B-1 after Failure.

Figure 9. End View of Model Z-3 after Failure.

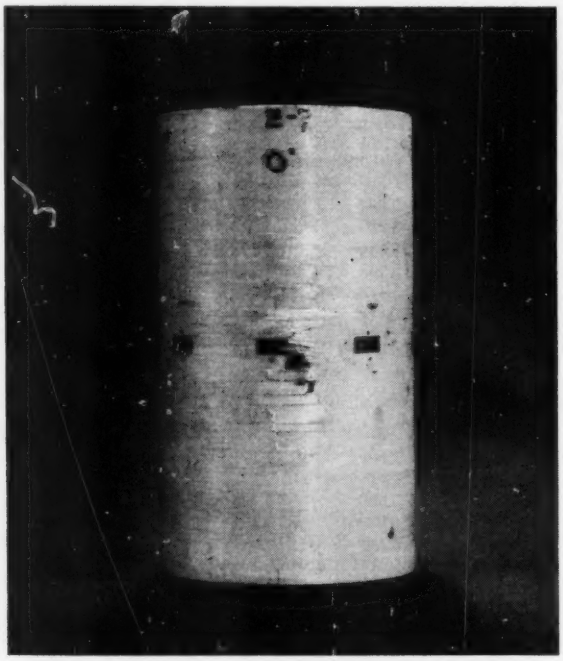


Figure 10. Exterior View of Model H-1 after Failure.

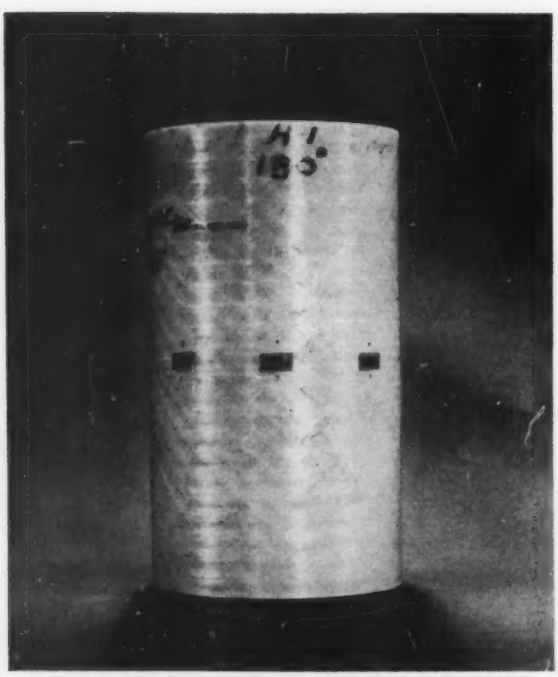


Figure 11. Exterior View of Model Z-7 after Falure.

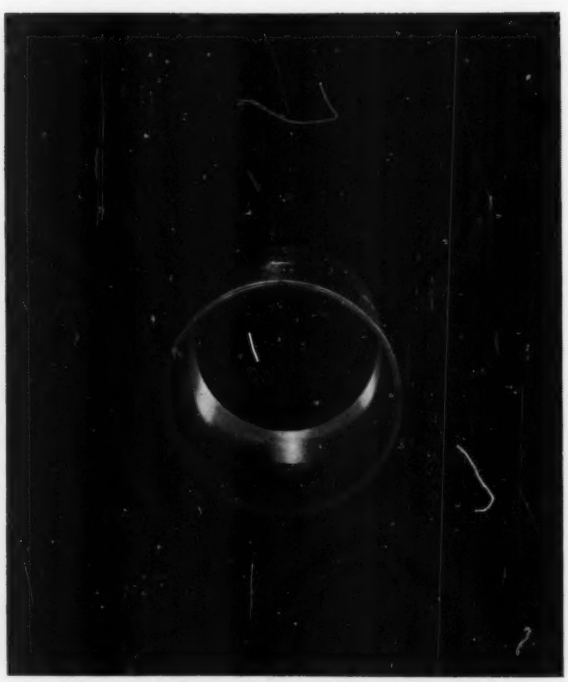


Figure 12. End View of Model B-3 after Failure.

stresses to compute two values of elastic modulus. An "effective modulus" was then determined and used to predict the elastic buckling pressure. The buckling pressures thus determined and a summary of the pertinent test results are given in Table 3. The corresponding information for Model ZP-3562 is included for comparison purposes.

An examination of Table 3 reveals that for the 7 models tested under short-term loading, the experimental collapse pressures agree within 5 per cent with the values predicted except in the case of Model H-1. Model H-1 failed at a pressure 26 per cent below that predicted from the elastic buckling equation, and appears to have collapsed prematurely either by virtue of its helical construction or some possible flaws in the cylinder. Some additional tests will be carried out to check these possibilities further.

Model Z-2, a duplicate of Z-1, was subjected to long-term loading at various pressure levels to investigate the creep characteristics and their cumulative effect on static collapse strength of GRP cylindrical shells. The highest pressure sustained was 3400 psi for 26 days. At this time the O-ring seal in the test tank failed, causing the pressure to drop to zero. After the O-ring was replaced, the pressure was again raised to 3400 psi. On this last pressure loading it was observed that the strain rate was greater than that on the previous loading to 3400 psi. The model sustained the 3400 psi for 27 hr before collapse occurred. The mode of collapse was similar to that of Model Z-1 except that some circumferential tearing occurred near the ends; see Figure 13.

Strain-time histories recorded from circumferen-

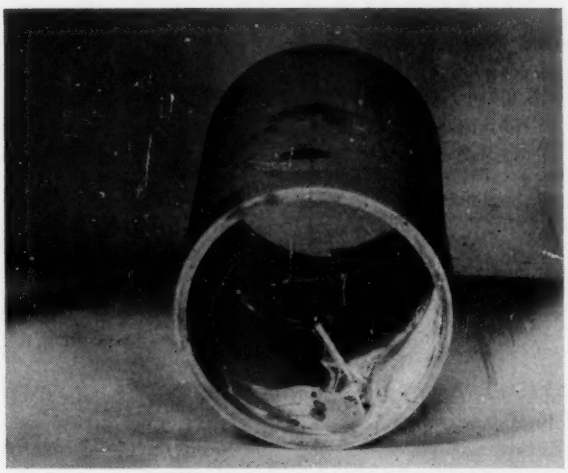


Figure 13. Interior View of Model Z-2 after Failure.

TABLE 3

Summary of Unstiffened Cylinder Model Test Results

Model Number Circumferential Strain	B-1	Z-1	ZP 3562	Z-3	Z-7	H-1	B-3	Z-2 Run 2	Z-2 Run 3
μin/in/psi									
Outside	1.53	2.07	1.69	1.15	2.61	3.12	2.81	1.78	2.01
Inside	1.75	2.40	2.04	1.35	2.79	3 31	3.16	1 96	2.21
Average	1.640	2.235	1.815	1.252	2.701	3.213	2.985	1.870	2.110
Longitudinal Strain μin/in/psi									
Outside	0.627	1.116	1.14	0.658	1.01	1.24	0.92	0.87	0.93
Inside	0.671	1.182	1.18	0.668	1.03	1.29	0.92	0.84	0.94
Average	0.649	1.149	1.160	0.663	1.024	1.267	0 934	0.855	0.935
Membrane Stresses, psi/psi									
Circumferential	9.884	10.105	10.146	8.535	17.156	15.584	17.309	10.105	10.105
Longitudinal	4.942	5.053	5.073	4.267	8.578	7.792	8.655	5.053	5.053
Modulus of Elasticity psi$\times 10^6$									
Circumferential	5.57	4.10	4.85	6.17	5.87	4.48	5.41	4.94	4.39
Longitudinal	5.40	3.82	3.44	4.90	5.87	4.35	6 12	4.35	3.95
Effective	5.50	3.99	4.38	57.5	5.87	4.44	5.65	4.74	4.24
Collapse Pressure, psi									
Computed Elastic Buckling, p_c	4890	3407	3674	7565	1281	1225	1199	4046	3621
Experimental, p_e	5000	3550	3735	7900	1325	910	1225		3400
Ratio of Collapse Pressures $\frac{p_e}{p_c}$	1.022	1.042	1.017	1.044	1.034	0.743	1.022		

tial gages near the region of failure of Model Z-2 are shown in Figure 14. An examination of these curves reveals that the "cycling" resulting from the loading sequence of 5 pressure runs to collapse resulted in significant changes in the straining. This is indicative of a reduction in the material properties, principally modulus, possibly resulting from either creep inherent in this material or mechanical breakdown of the bond between the fibers and the resin. The reduction in moduli resulting from the long-term loading is also reflected in the loss of ultimate load-carrying capacity as shown in Table 3.

In addition to the tests of unstiffened cylinders discussed above, two ring-stiffened cylinders, Models ZR-1 and ZR-2, were designed according to the criteria used in developing the curves of Figure 3. These two models had approximately the same weight-volume characteristics as the unstiffened cylinders ZP-3562 and Z-1. Model ZR-1 had a 2C: 1L shell construction whereas Model ZR-2 had a 1C: 1L shell construction; however, both had the same geometry and, in particular, both had end frames which had 3 times the area of a typical frame. Model ZR-1 failed at a pressure of 5400 psi whereas ZR-2 failed at 6000 psi. The failed models are shown in Figures 15 and 16, respectively. It is significant to note that both cylinders failed near the end regions indicating that the full strength of the typical portions was not realized. The design collapse pressure was on the order of 6500-7000 psi. The apparent reduction in strength can be attributed to the rather rigid end frames incorporated in the design. This will be discussed further in connection with similar tests conducted by the Zenith Plastics Company, in which different size end frames were employed.

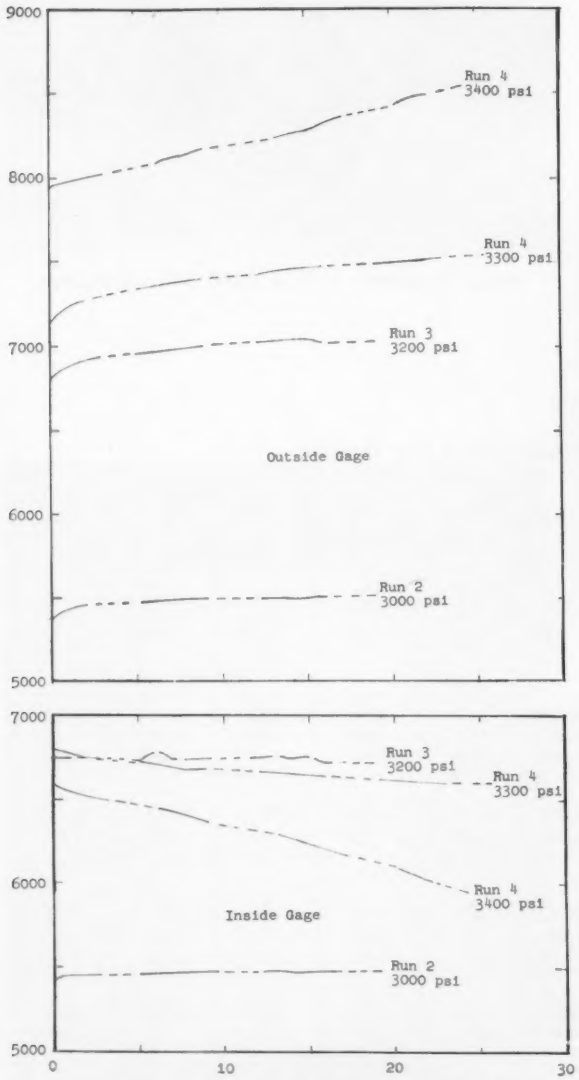


Figure 14. Strain-Time Plots for Circumferential Gages on Model Z-2.

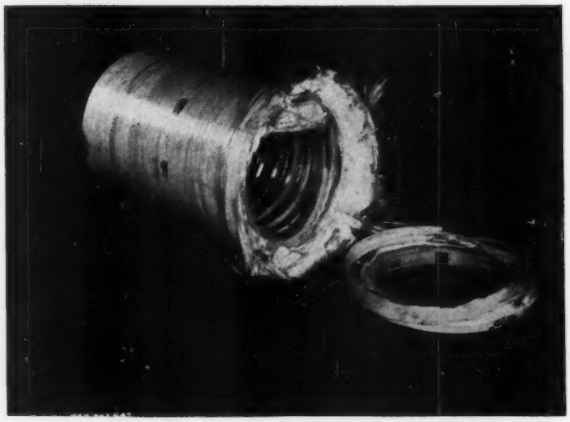


Figure 15. End View of Model ZR-1 after Failure.

Figure 16. End View of Model ZR-2 after Failure.

MODEL TESTS BY ZENITH PLASTICS COMPANY*

The Zenith Plastics Company has fabricated and tested, at their own expense, 38 unstiffened cylinders of approximately 6 in. inside diameter. The cylinders were fabricated from various glass-fiber reinforced epoxy-resin tapes manufactured by their parent company. The test results of the cylinders having a 2C:1L buildup and a wall thickness of approximately 0.31 in. are shown in Figure 17. Curves of the elastic buckling pressure computed for assumed Young's moduli of 4×10^6 psi and 5×10^6 are shown for comparison. The large spread in experimental collapse pressures can generally be attributed to variations in the modulus of elasticity due to the glass content of the cylinder. The glass content ranged from about 69 per cent to 84 per cent; the cylinders with the higher glass content had the higher collapse pressures.

The Zenith Plastics Company has also fabricated and tested, at their own expense, 9 ring-stiffened cylinders. Six of these tests were conducted using models with the typical geometry of Models ZR-1 and ZR-2. In the 6 tests the type of material was varied as were the end conditions and the fiber distribution through the shell thickness. Four of the models had shells with a 2C:1L fiber distribution and 2 with a 1C:1L fiber distribution. The rectangular ring stiffeners were machined from tape-wound tubing having from 90 to 100 per cent circumferential fibers. The highest collapse pressure realized was 7300 psi for a cylinder having a 2C:1L shell and the next highest collapse pressure was 6500 psi for a cylinder having a 1C:1L shell.

The typical center portion of these models was designed by the Model Basin assuming the material had a strength of 70,000 psi and a Young's modulus of 4.8×10^6 psi. It is estimated that the material in the shells of the models that failed at 7300 psi and 6500 psi had a strength of approximately 90,000 psi and a Young's modulus of approximately 6×10^6 psi and the rings had a strength in excess of 100,000 psi and a modulus of approximately 9×10^6 psi.

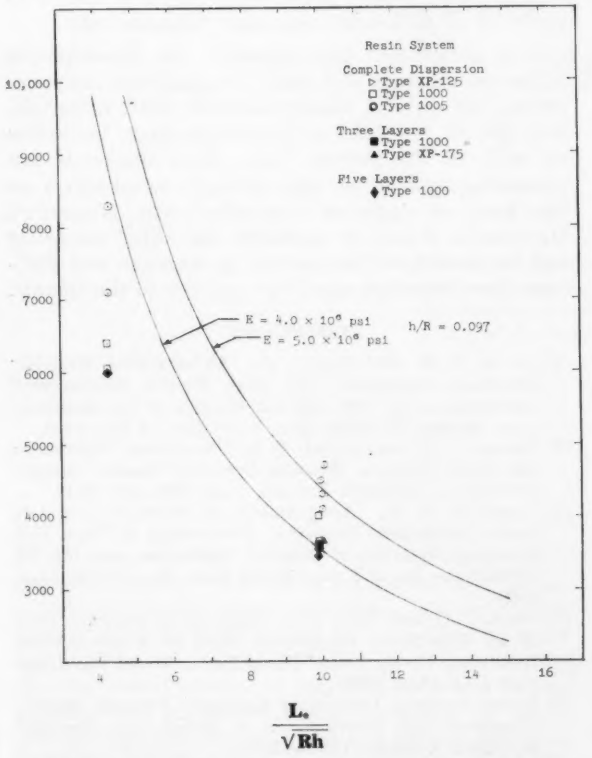


Figure 17. Buckling Collapse of Unstiffened Zenith Cylinders (2C:1L).

DISCUSSION AND CONCLUSIONS

It should be emphasized that the GRP materials presently being investigated as part of the Model Basin program were not developed for the specific purpose of pressure vessels subjected to high external pressure. Thus, they are not representative of the ultimate composite material for such application.

The strength-weight curves of Figure 3 for the GRP materials are based essentially on the ultimate strength of *Commercially available* filament-wound GRP materials. On the face of it this would seem to be reasonable since the curves for the other materials were based on yield strength (and allowing for the plastic reserve strength to be developed) and it is true that GRP does not indicate a yield point. There is concern, however, about the effects of cyclic fatigue and long-term exposure to deep-submergence pressures on the load-carrying capacity of filament-wound structures and consequent limitations in design allowable. Much work must be done in these areas with regard to determining the design limitations for filament-wound structures subjected to deep-submergence pressures.

Nevertheless, the general information now available on various GRP materials subjected to long-term and cyclic loading gives ample reason for vigorous prosecution of Research and Development programs to improve the characteristics of these materials. For example, there has been a considerable amount of information obtained on the effect of cyclic fatigue (tension-compression) on various laminates under different conditions. Such tests indicate that there can be better than a 50-per cent reduction in strength (based on short-term compression strength) after 50,000 cycles. With regard to long-term loading, the Forest Products Laboratory [5], has reported failures of unidirectional

*This information is presented here with the generous permission of the Zenith Plastics Company. The results given were obtained during research conducted by Zenith as part of a no-cost arrangement with the Bureau of Ships and in collaboration with the David Taylor Model Basin.

glass-reinforced epoxy laminates after immersion in water under flexural load equivalent to 56 per cent of the short-time flexural strength for 1000 hours. It is obvious that such reductions, if they prove to be necessary in the design of filament-wound pressure hulls, will greatly reduce the advantages of such materials.

In seeking to obtain improved laminate characteristics it is important that the resin-interface-glass reinforcement be considered as a system. To date, it appears that the improvement of resins has received too little attention, possibly for lack of new or original approaches to the problem. While it has not definitely been established which particular characteristics it would be most important to improve, for the particular application to deep-submergence hulls, higher compressive strength and modulus, greater affinity of resin to reinforcement, as well as improved resistance to shear and delamination, seem necessary. The resin must provide greater stability to the glass filament and greater resistance to catastrophic failure.

Much work has already been done in the area of improved glasses and finishes, but specific resin-interface-glass systems must be evaluated extensively before we can appraise the value of these new reinforcements. Certainly there still seems to be room for much more effort to improve reinforcement.

Because of the low modulus of elasticity of GRP compared to that of steel the possibility of sandwich-type construction to increase the cross-sectional stiffness is also intriguing and deserving of investigation. Here, the strength characteristics of available core materials are a limitation. Lightweight, high-strength core materials, resistant to water penetration under high hydrostatic pressures, are needed.

Finally, confidence levels must be established to give the designer assurance that the materials in the hull structure will perform in accordance with established design criteria. Quality control practices and inspection test techniques must be devised to give this assurance.

Hull form is another factor which requires investigation. The thought has been widely advanced that shapes other than cylindrical with spherical ends might provide improved resistance to external pressures. Various unconventional, complex configurations have been suggested. Such shapes would be extremely difficult if not impossible to achieve with the high-strength metals, but could be fabricated easily using GRP.

The Bureau of Ships is supporting material research efforts in some of the above areas. The Material Laboratory, New York Naval Shipyard, has been investigating the basic mechanisms of failure for glass-reinforced laminates. It is hoped that from this effort may come better direction and guidance for future materials research programs. The Laboratory has also been working on development of test methods that will provide standards for evaluation of materials and relate these to the type of loading conditions experienced under external hydrostatic pressure. Inspection and nondestructive test techniques are also being investigated.

A program to study resin-interface-glass reinforcement systems under carefully controlled laboratory conditions is being sponsored to develop materials which have improved compressive strength and modulus.

The David Taylor Model Basin is conducting a broad investigation of filament-wound cylindrical structures made of *commercially available* materials to determine response to external pressure loading and to obtain design information on such details as methods of stiffening, openings, closures, etc.

It is anticipated that research and development in the above areas will result in significant improvements, not only in filament-wound GRP materials, but also in the field of general-purpose laminates as well. At the present time, these materials are competing against the high-strength metal alloys on the basis of superior strength-weight properties. Ultimately, it can be expected that GRP materials will be developed demonstrating strength and stiffness characteristics equal or superior to the metals.

REFERENCES

[1] Owen, T. B. and Sorkin, G., "Metallurgical Materials Problems Associated with Deep Diving Submarines," presented at the 1960 Annual Meeting of the Metallurgical Society of AIME, New York City, 14 Feb. 1960.

[2] Barnet, F. R. and Lloyd, C. L., "Reinforced Plastics in the Construction of External Pressure Vessels," Society of Plastics Engineers Journal, Aug. 1956, pp. 15-19.

[3] Lunchick, M. E., "Yield Failure of Stiffened Cylinders under Hydrostatic Pressure," Proceedings of Third U.S. National Congress of Applied Mechanics, pp. 589-594 (1958); also David Taylor Model Basin Report 1291 (Jan. 1959).

[4] Pulos, J. G. and Buhl, J. E., "Hydrostatic Pressure Tests of an Unstiffened Cylindrical Shell of a Glass-Fiber Reinforced Epoxy Resin," David Taylor Model Basin Report 1413 (Apr. 1960).

[5] Forest Products Laboratory Quarterly Progress Report, "Research and Development in Reinforced Plastics," BUSHIPS Contract/1700S-635-59.

LENNART PEHRSSON and ROBERT G. MENDE

DESIGN, MODEL TESTING AND APPLICATION OF CONTROLLABLE PITCH BOW THRUSTERS

ACKNOWLEDGMENT

This paper written by Mr. Lennart Pehrsson of AB Karlstads Mekaniska Werkstad and by Mr. Robert G. Mende of the Bird-Johnson Company was presented at a meeting of the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers on 29 September 1960.

FOR DECADES SHIP designers and operators have accepted the fact that the combination of conventional rudder and screw propeller has provided a degree of maneuverability at low speeds of advance which is something less than desired. More recently, the directional control of large single screw vessels and the need for superior maneuverability of many special ship types at low speed has focused attention on the need for auxiliary steering devices. Such devices have been labeled "lateral thrusting bow propellers," "transverse bow propellers," "bow steering propellers," "bow jets," "athwartships bow propellers," "right-angle steering propellers" and somewhat facetiously, "side-winders." Although each of these names is variously accepted, U.S. preference is for the simpler and somewhat generic term "bow thruster."

REQUIREMENTS OF A BOW THRUSTER

In order to assess the fundamental requirements of a bow thruster let us first examine the needs of several ship types:

Large single screw merchant vessels (including tankers, ore and bulk carriers, dry cargo ships, etc.) achieve some degree of control of their stern movement at low speed by use of rudder angle and main propulsion slip stream. At the same time the bow is virtually uncontrolled and should an unfavorable tide, current or wind exist particularly in conjunction with trim by the stern, the consequences in restricted waters could be disastrous or at the very least embarrassing. Quick application of a transverse force of sufficient magnitude at or near the bow could correct the undesired swinging of the

ship's head. Also, if such a vessel is engaged in a trade which requires regular transit of narrow, tortuous channels or a lock-system such as the St. Lawrence Seaway, the value of an auxiliary steering force is obvious. In addition, there are a number of large merchant vessels occupied in important trade in small, out-of-the-way ports that frequently lack adequate or reliable tug assistance. A bow thruster can greatly increase the self-sufficiency of such ships.

Special purpose ships as a category covers a great deal of ground; however several specific examples are worth particular mention. *Buoytenders* are faced with the often hazardous task of coming alongside and hovering close aboard huge buoys which the deck crew must service in all kinds of weather. A transverse force at the bow which could be rapidly and easily varied in magnitude and direction would greatly minimize the chances of injury to personnel and the vessel. *Large rail ferries* and *roll-on, roll-off ships* customarily load and discharge over the bow or stern at special terminals requiring accurate positioning of the vessel. A self-contained transverse maneuvering force can speed up the docking operation and eliminate a great deal of warping with wires. *Cable ships* must operate at low speed and maintain an accurate course for days at a time while laying cable. An auxiliary maneuvering device is virtually mandatory in that service.

Research vessels of all types— oceanographic, hydrographic, fisheries, etc. frequently operate at very low speeds of advance while attempting to hold a precise course and simultaneously manipulate submerged instruments. This too calls for a degree of maneuverability not commonly found on even the majority of twin screw vessels. Operational requirements for certain *military ships* often embody the need for precise station keeping at a fixed location, accurate course tracking at very low speed, precise maneuvering for the transfer of materiel at sea and superior maneuverability around a congested beaching operation. For all such purposes the bow thruster can be a valuable augmentation of the vessel's conventional steering system.

Fast passenger liners that travel between major deep water ports are not usually considered candidates for low speed maneuverability. However, interruption of tug services due to disputes of one sort or another are not unheard of and a liner equipped with a bow thruster would be quite comforting to her owners. In addition, the advantages of low speed maneuverability under all circumstances would be acquired.

Integrated river tows are often longer than our largest deep water ships and yet are faced with navigating the twists and turns of a very restricted river channel. A natural application of the bow thruster would be in the lead barge of such an integrated tow, providing of course that control of the unit was maintained in the towboat pilothouse.

Therefore, considering these possible applications it is suggested that the fundamental requirements for a bow thruster are as follows:

1. Maximum thrust must be available quickly in response to an order.
2. Performance of the unit must be identical for either thrust to port or thrust to starboard.
3. Thrust reversal must be as rapid as possible.
4. Thrust must be controllable in magnitude, from zero to maximum in both directions.
5. The unit must be readily suitable for remote control from one or more stations.
6. The unit must be reliable, easily installed and of rugged construction.

BASIC DESIGN

There are several basic design solutions which meet all or most of the bow thruster requirements. Although it is not the purpose of this paper to discuss each of these designs and their variations, they have all had limited application and warrant identification by type as follows:

Right angle drive—variable speed—fixed propeller (single or counter rotating)

Submerged motor—variable speed—fixed propeller

Vertical axis propeller

Axial flow pump with valved ducts

Controllable pitch propeller

It is the latter type—the "CP bow thruster" which forms the basis for the remainder of this discussion.

A thoughtful review of the requirements listed in the preceding section leads to the logical conclusion that the remotely controlled, unidirectional rotation, controllable and reversible propeller is ideally suited to bow thruster application. In actual practice a vessel so equipped would start the CP bow thruster rotating in a "zero thrust" position as a maneuvering situation was approached. Thereafter, response to a thrust order is virtually instantaneous. Magnitude of the thrust delivered is infinitely variable between zero and maximum to either side. Thrust reversal is extremely rapid since there is no necessity of absorbing the momentum accompanying the reversal of rotation. Incidentally, the speed of thrust reversal is of prime importance since under certain conditions it may become necessary to quickly check the swing of the ship's head. The reliability and ruggedness of the controllable pitch propeller is a proven fact today. Its mechanism in main propulsion has withstood the tests of 20,000 SHP, the stresses of super-cavitating performance and the abuse of ice-breaking service. Acceptabili-

ty in bow thruster service should be unquestioned.

The prime mover for the CP bow thruster may be Diesel engine, steam or gas turbine or AC or DC electric motor. This is largely a matter of owner preference. It is interesting to note however that the majority of present installations have been with constant speed AC electric motors. This choice is particularly well-suited to the CP bow thruster as variable speed controls are not required and with the blades in "zero thrust" position the motor starting current is kept low. Also, the total generator capacity of some ships is determined by a cargo handling operation and is in excess of normal underway requirements. This "excess capacity" can be put to use by the bow thruster during maneuvering.

Recent discussions with a prominent tanker operator who is considering the application of CP bow thrusters revealed his concern for the vulnerability of any steam or electrical machinery located in the forebody which in the event of a casualty could be rendered useless by fractured supply piping or cables. This consideration makes the independence of a diesel or gas turbine prime mover decidely advantageous. Also it is likely that the diesel will be the favored prime mover for a CP bow thruster installation on an existing vessel where the generator capacity is inadequate to handle the additional load.

MODEL TESTS

Early in the development of the CP bow thruster a series of model tests was conducted in the cavitation tunnel of the KaMeWa Propeller Laboratory. The goal of these tests was to determine the influence of blade area, number of blades, configuration of duct openings, guide vanes and grids on the thrust produced. A special testing arrangement was constructed to approximate both the duct in which the bow thruster operates and the ship's side shell plating in the immediate vicinity of the hull opening. The duct was connected to a scale so that axial forces acting on it could be measured directly. Thrust and torque of the propeller were measured with the usual tunnel instruments. This arrangement is shown in Figure 1.

Three controllable pitch and one fixed pitch propeller models were tested. All four models were of the Kaplan type, i.e., the blade tip has the form of a circular arc. The CP blades were planar (zero design pitch) and had symmetrical NACA 16 sections. The fixed propeller was designed with a constant pitch ratio of 0.70 and had bisymmetrical NACA 16 sections. Clearance between the blade tips and tunnel wall was 1.5 mm, except of course when the CP blades were adjusted for positive or negative pitch and the clearance increased at the blade edges. The data for the model propellers is

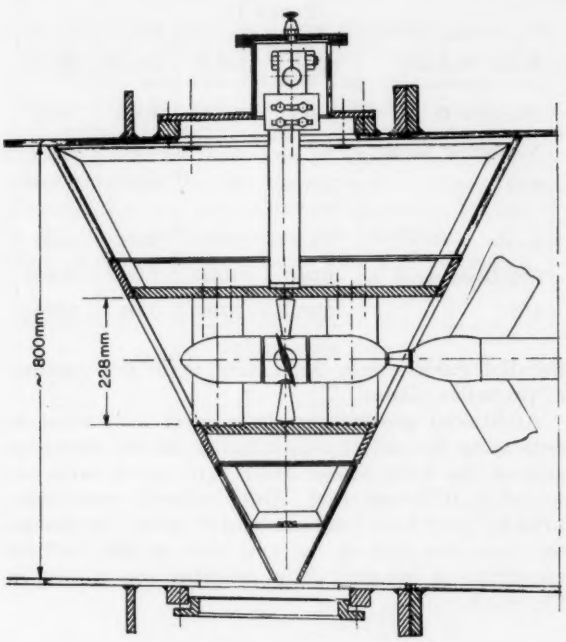


Figure 1. Testing Arrangement.

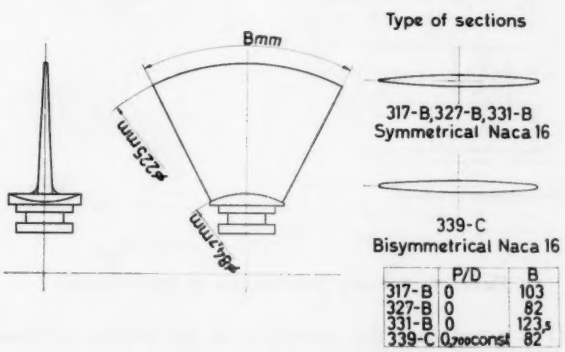


Figure 2. Model Propellers.

shown in Table I and the blade designs are shown in Figure 2.

Prior to systematic testing of the complete series, several preliminary tests were conducted using Model 317-B. One set of these tests was to determine the influence of various guide vane arrangements and included investigation of one, three and six guide vanes at each end of the bow thruster pod. The test with three guide vanes was further varied to determine the influence of 0, 5 and 10 degree angle of attack on the guide vane configuration. The latter test indicated that for a given horsepower the total thrust produced varied only 2-3 per cent except at large angles of attack where the thrust loss was unacceptable. Therefore it was determined to standardize on an arrangement with three or four

TABLE I

Model Number	317-B	327-B	331-B	339-C
Diameter D, m	0.225	0.225	0.225	0.225
Number of Blades	4	4	3	4
P/D	0 (planar blades)	0	0	0.700
A_E/A_O	0.500	0.432	0.450	0.432
Hub Diameter d, m	0.0847	0.0847	0.0847	0.0847
d/D	0.376	0.376	0.376	0.376

parallel guide vanes depending upon the number of propeller blades.

Additional preliminary tests were conducted to determine the velocity distribution at the discharge side of the duct. Model 317-B with pitch ratio adjusted to 0.70 was used. Water velocity was measured by pitot tube located about ¾ propeller diameter from the end of the pod and on the vertical centerline of the duct. The velocities are plotted in Figure 3.

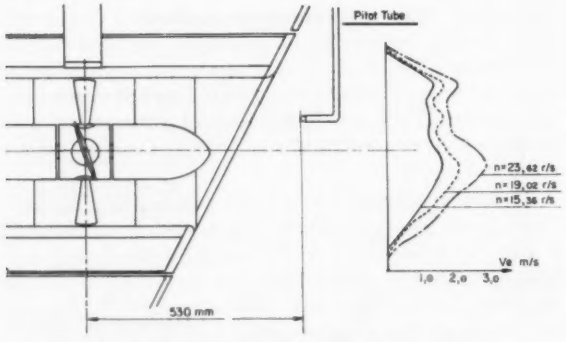


Figure 3. Velocity Distribution at Duct Outlet.

It is noted that the velocities at the bottom of the duct are lower than at the upper part of the duct. This is primarily due to the fact that the pitot tube was at a greater distance from the end of the duct at the bottom than at the top.

Also conducted were streamline tests which indicated that the flow in the lower part of the duct was somewhat unstable. In an effort to improve this situation, a bulge was arranged at each end of the duct, see Figure 4.

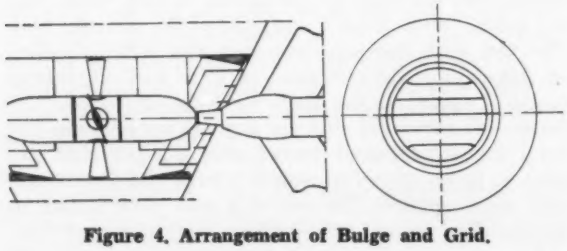


Figure 4. Arrangement of Bulge and Grid.

This increased both K_T and K_Q of the propeller, but surprisingly caused the axial force on the duct to become negative. This result is illustrated in Table II for a bow thruster of 1.3 m. diameter and 285 DHP-metric:

TABLE II

Test Number	15 (without bulge)	16/17 (with bulge)
P/D	0.7	0.59
RPM	398	389
T Propeller	kg 2816	3560
T Tunnel	kg +409	—840
Total Thrust	kg 3225	2720

Additional tests on the effect of such bulges will be conducted in the cavitation tunnel in the near future. It was determined however that grids (see Figure 4) installed at the duct openings exerted a stabilizing effect on the flow and these were included in the finally accepted arrangement.

The final systematic series of model tests was conducted with three and four guide vanes for four bladed and three bladed propeller models respectively. The openings of the duct were free, i.e., no grids were used for this series. Check tests indicate that the addition of grids increases the total thrust by 1.5-2.0 per cent.

A comparison of the four propeller models tested is shown in Figure 5, from which several observations can be made. The three bladed Model 331-B with blade area ratio of 0.45 is slightly less efficient than the four bladed reference Model 317-B with blade area ratio of 0.50. There was no significant

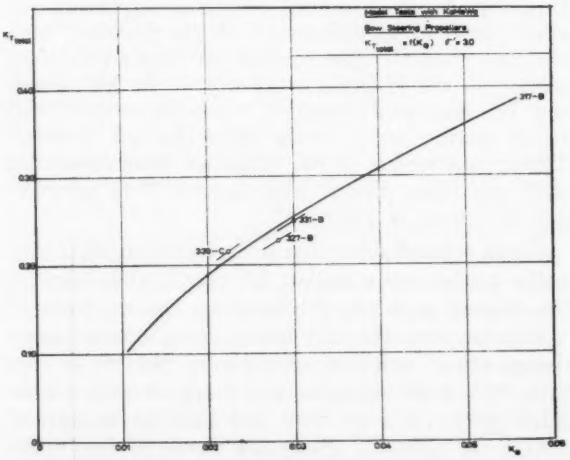


Figure 5. Model Tests of KaMeWa Bow Thrusters.

difference in the cavitation pattern between these two.

The four bladed Model 327-B with blade area ratio of 0.432 is inferior to Model 317-B by about 6.5 per cent. Model 327-B differs from Model 317-B only with respect to blade area ratio and as could be expected, Model 327-B showed more cavitation.

The fixed pitch propeller, Model 339-C, which differs from 317-B primarily in having bisymmetrical sections and a helicoidal surface, indicates an improvement in K_T-total of about 3.9 per cent. Considering that the CP propellers have planar blades and therefore an unusually high load at the tips, this superiority of the fixed pitch propeller may appear small. However, as in a Kort nozzle, the duct walls reduce the loss over the blade tips, and this effect is more pronounced and therefore more favorable to the planar bladed CP propeller with highly loaded tips. Also, the cavitation of Model 339-C was somewhat less than the other models.

The cavitation pattern observed with the four models is shown in Figure 6. As usual in a static pull condition, the cavitation appears as sheet cavitation extending from the blade tips toward the hub. The guide vanes were free of cavitation.

A question often raised concerns the degree of increased hull resistance due to the introduction of a discontinuity such as a bow thruster tunnel. Obviously such factors as hull form, speed and draft plus depth, size and shape of the discontinuity all influence the problem. Several specific ship designs with which the authors have had contact were resistance tested to determine an answer to this question. Although the results are not universally applicable, they are presented in Tables III, IV and V to give an order-of-magnitude indication of the affect of a bow thruster tunnel on hull resistance.

TABLE III

GREAT LAKES TYPE BULK CARRIER

LBP	— 712′-0″
Beam	— 75′-0″
Draft (loaded)	— 26′-6″
Draft light)	— 8′-0″ Fwd.; 20′-0″ Aft
C_B	— 0.865

a. With bow tunnel only

Tunnel Diameter	— 6′-0″
Tunnel Location, C.L.	— 26′-0″ Aft of F.P. 8′-0″ above B.L.

V knots	11	12	13	14	15	16
Percent Increase in Resistance Loaded Ship	0	0.3	0.4	0.4	1.5	0.8
Percent Increase in Resistance Light Ship	0.3	0.3	0.6	0.9	0.9	0.8

b. With bow tunnel plus stern tunnel

Bow tunnel as (a) above	
Stern tunnel diameter	— 5′-0″
Stern tunnel location, C.L.	— 31′-6″ Fwd of A.P. 7′-6″ above B.L.

V knots	11	12	13	14	15	16
Percent Increase in Resistance Loaded Ship	0.1	0.4	0.8	1.9	3.0	1.7
Percent Increase in Resistance Light Ship	0.6	0.5	1.3	2.5	2.4	2.0

TABLE IV

SMALL PASSENGER VESSEL

LBP	— 270′-0″
Draft	— 13′-5″
C_B	— 0.575
Tunnel Diameter	— 4′-3″

V knots	16	16.5	17	17.5
Percent Increase in Resistance	0.9	1.6	1.7	1.7

TABLE V

DRY CARGO VESSEL

LBP	— 530′-0″
Beam	— 93′-0″
Draft	— 25′-0″
Tunnel Diameter	— 4′-6″
Tunnel Location, C.L.	— 38′-0″ Aft of F.P. 10′-0″ above B.L.

V knots	18.5	20	21
Percent Increase in Resistance	0.2	0.1	0.1

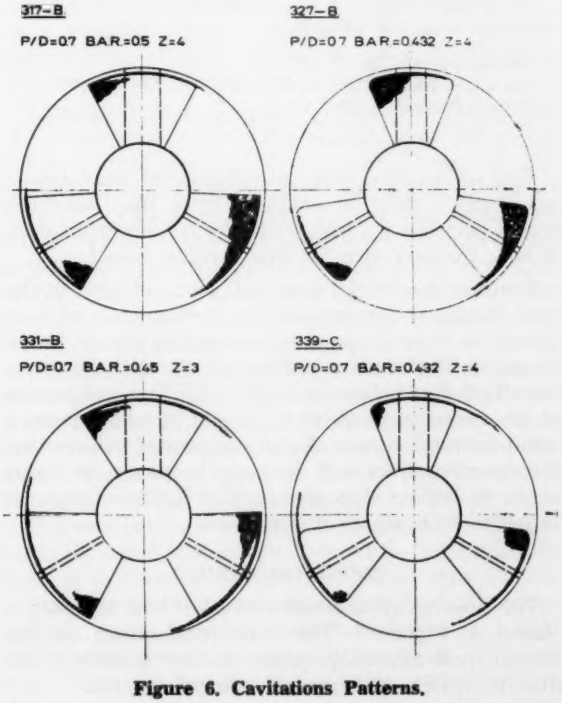


Figure 6. Cavitations Patterns.

Generally, it appears that the increase in resistance is quite small; however in the case of the full-bodied bulk carrier there is a peak in the higher speed range. The exact reason for this is unknown, but it is suggested that a study of the wave profiles or a determination of the pressure variations along the length of the hull would reveal a contributing relationship. If that were true, it is likely that a judicious location of the transverse tunnel would minimize the affect on resistance and in most cases keep it well below a one per cent increase. For bow thruster application on very fast ships it might be desirable to fit retractable doors over the tunnel openings. It is understood that a fast passenger vessel now under construction in Great Britain is so equipped.

As mentioned earlier it is recognized that a maneuvering force may have to act to swing a ship's head against a total resistance composed of wind, current, waves and its own lateral resistance to pivoting. In order to obtain some indication of the lateral pivoting resistance in still water, the bulk carrier model mentioned earlier was further tested. The results which were obtained are shown in Table VI.

TABLE VI

BULK CARRIER—PIVOTING

Time to Pivot 90 Degrees, Minutes	4	8	12
Moment in Ft-Lbs $\times 10^6$ for Loaded Ship (Pivot Point 378' aft F.P.)	16.2	4.2	1.9
Moment in Ft-Lbs $\times 10^6$ for Light Ship (Pivot Point 383' aft F.P.)	7.6	1.9	0.9

This information plus an estimate of wind resistance, which may be obtained from the literature, would provide a sound basis for the determination of bow thruster size for this specific vessel.

Further ship model tests will be conducted in the near future to investigate the performance of bow thrusters when a vessel is proceeding slowly ahead or astern. Preliminary indications are that the steering effect diminishes gradually with forward motion of the vessel until about 6-7 knots at which point a rapid decrease occurs. Some authorities believe that the steering effect will recover its maximum value again at higher ship speeds, but further testing is required to evaluate this opinion.

DESIGN DESCRIPTION

The general arrangement of a CP bow thruster is shown in Figure 7. The basic components are the tunnel, pod assembly, prime mover assembly, hydraulic system and remote control system.

The tunnel is fabricated of a single rolled plate or of inner and outer plate construction to permit withdrawal of the entire tunnel and pod assembly. Where single plate tunnel construction is used it is possible to remove propeller blades without disturbing the pod or guide vanes. Material used is mild steel, stainless steel or stainless clad plate depending upon the service and operator's preference.

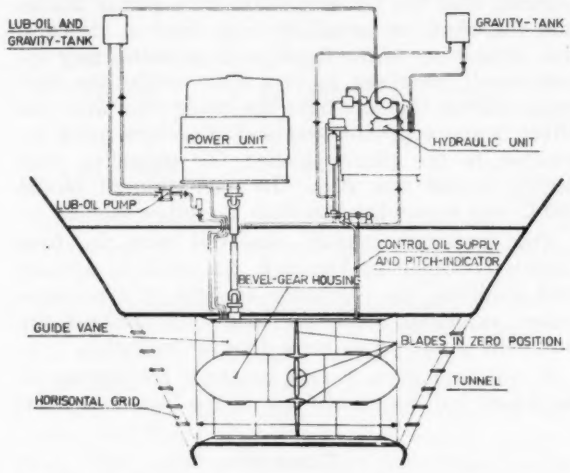


Figure 7. General Arrangement of CP Bow Thruster.

The pod assembly, see Figure 8, includes the guide vanes, pod housing, bevel drive gears, stub shaft, thrust bearing, lip-type shaft seals, KaMeWa controllable pitch propeller hub, hydraulic oil distribution box and propeller blades. One guide vane at the drive end of the pod houses the drive-shaft (either horizontal or vertical depending upon location of the prime mover) and gear lubrication fittings. One guide vane at the opposite end of the pod is used to house the hydraulic lines and pitch follow-up equipment. It will be noted that the pod has a rather large diameter in relation to the propeller. Diameter—approximately 0.41 D. This is required solely in order to accommodate the bevel gear and bears no relation to the CP mechanism, i.e., pod diameter will be identical for either a fixed pitch or controllable pitch design.

The prime mover is connected to the bevel gear pinion in the pod by means of a drive shaft fitted with universal joints at both ends. That section of drive shaft within the guide vane is connected to the external section of shaft with a dental type toothed coupling to permit slight axial and angular misalignment at installation.

The hydraulic system is a basic controllable pitch propeller system consisting of a sump tank, gravity tank, motor driven positive displacement pump and appropriate hydraulic valves.. The pitch actuating spool valve is positioned either by a solenoid or pneumatic positioner depending upon whether the

remote control system is electrical or air actuated. Generally the prime mover is started locally although this may be handled from the bridge or engine room if desired. Pitch control is normally arranged for bridge operation with local control also available when necessary. Pitch indicators are located at each control station. An interlock is provided to prevent starting the prime mover if the propeller blades are not in a zero pitch position.

The CP bow thruster can be built to accommodate any reasonable prime mover horsepower; however the series shown in Table VII has been tentatively established. This series may be revised if the demands of the marine industry indicate it is necessary and desirable to do so.

TABLE VII

Horsepower	Diameter	RPM	Thrust—Lbs
150	3'-7"	450	4,500
300	4'-3"	420	7,900
500	5'-5"	340	13,200
800	6'-7"	290	20,400
1200	7'-11"	240	30,200
1800	9'-2"	210	44,100

These data should be considered as approximate since a certain amount of judicious variation of power, diameter and RPM is permissible without seriously affecting the delivered thrust.

Figures 9-12 illustrate several CP bow thrusters in final assembly, under shop test and as installed.

TRIALS, SERVICE AND APPLICATION

The first 300 HP KaMeWa CP bow thruster was installed on the 365 ft. LOA passenger and rail ferry *Princesse Benedikte*. Diameter is 4 ft. 3 in. and the four blades of Model 317-B type. Performance trials resulted in 299 HP, 394 RPM and 7650 pounds thrust at a pitch setting of P/D=0.795. This indicates K_Q=0.033 and K_T=0.270 at σ'=3.0. These coefficients result in P/D=0.73 in each case. Obtaining this same pitch ratio indicates that while the prediction of power and thrust from the model tests was very nearly correct, the prediction of pitch was 9 per cent low. This trial was conducted with the stern of the vessel secured to the quay and the hull extended and restrained at about a 15 degree angle. A circulation of water was observed to be set up around the forebody and it is likely that this contributed to the higher pitch setting.

It had been expected that the thrust and torque might have been influenced by scale effect. The scale effect of friction was calculated to reduce torque by 2-4 per cent, the effect of tip clearance was figured to increase thrust by 3 per cent and, further, the presence of the grid was expected to increase thrust by 1.5-2.0 per cent. This would result in a total of approximately 7.5 per cent thrust increase over that

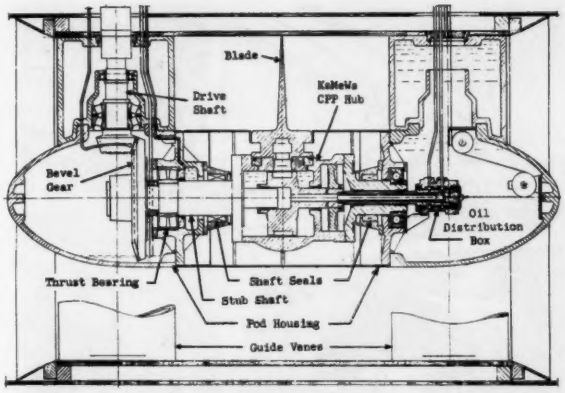
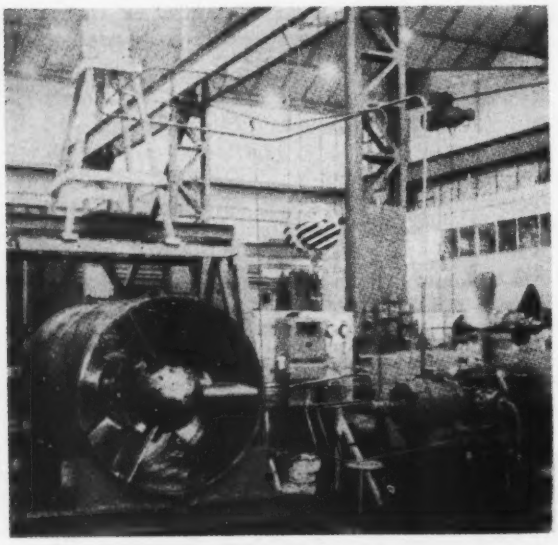


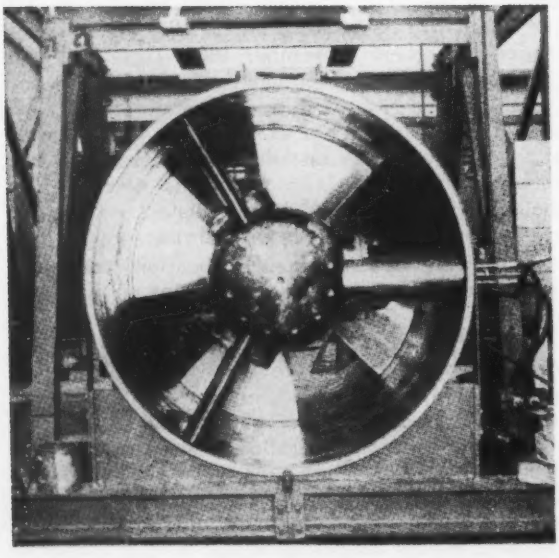
Figure 8. Pod Assembly.

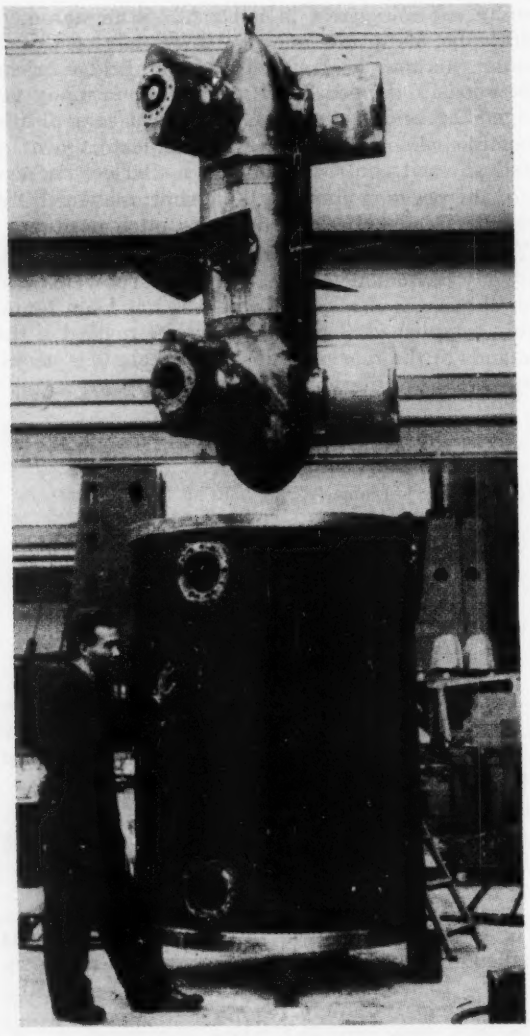
obtained from the model tests. Although the *Benedikte* trials did not bear this out, later trials with the identical type and size CP bow thruster on the 285′ LOA passenger and rail ferry *Princessan Christina* indicated a thrust of well over 8,800 pounds.

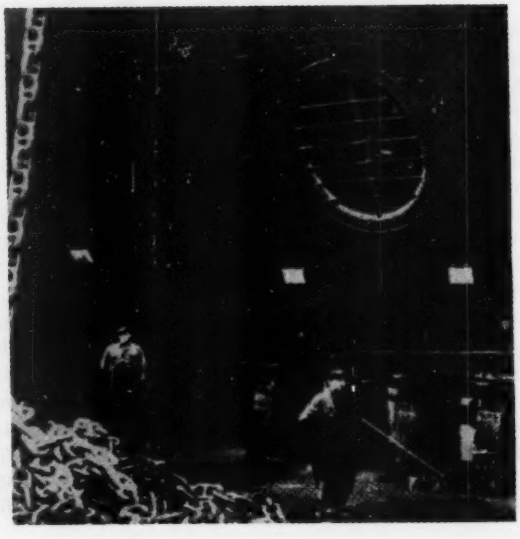
Service experience obtained over the past year and a half with this type of CP bow thruster has been extremely satisfactory. Four units are currently in service and seven more will be installed within the coming months. Included in the latter group is the first U.S. manufactured unit of 150 HP which will be installed on the 180′ USCG buoytender *Laurel* in November 1960. Operation has been found to be exceptionally free of noise and vibration. The ease of shipyard installation has exceeded expectations. For example, the pod assembly of the first unit was installed in the vessel in just about two hours. It is interesting to note too that the majority of the CP bow thrusters referred to are for operation in ice-going service.

Concerning bow thruster application, one question is paramount from the viewpoint of the naval architect and that is "how much thrust is required?" The model test data for the pivoting moment of a bulk carrier previously noted should be helpful for that class of vessel; however experience is still the best barometer of how much thrust is needed. Another consideration is where the thrust should be applied. The generally accepted location for a bow thruster is as far forward and as low as possible in the ship's forebody, with the minimum depth of tunnel centerline equal to the diameter. Normally a bow thruster is located forward where space is available and the force generated will act on the longest moment arm from the pivot point. This is not to say however that a bow thruster (or in this case perhaps a better name would be "transverse thruster") cannot be located in the stern sections of a vessel if desired for special reasons. An installation aft is entirely feasible but entails more difficult space problems particularly on a single screw vessel due to conflict with the shaft line in an area where the sections at the lower waterlines are









Figures 9 and 10 (above)—
Shop Testing CP Bow Thruster
Fiure 11 (top right)—
Final Shop Assembly CP Bow Thruster
Figure 12 (right)—
300 HP CP Bow Thruster as Installed

quite fine. A stern installation on a twin screw vessel would not be as difficult, but it would be desirable to direct the transverse thrust away from propeller shafts, bossings or struts.

As an empirical guide to the selection of required thrust it is possible to relate the force to the areas of the longitudinal planes of resistance both above and below the waterline. An examination of eleven bow thruster applications reveals that the pounds thrust per square foot of longitudinal plane below the waterline ranges from 0.65 to 4.02. For superior maneuverability a value of at least 3 lbs/sq. ft. is recommended and relatively adequate maneuverability is attainable with anything above 1.6 lbs/sq. ft. The pounds thrust per square foot of longitudinal plane above the waterline ranges from 0.58 to 2.67. It is felt that any value from 1.0 lbs/sq. ft. up should be satisfactory.

In conclusion, the authors wish to reaffirm their conviction that the use of CP bow thruster devices as a means of augmenting the maneuverability of all types of vessels will become more commonplace in the immediate future. This opinion is based on discussion and correspondence with ship designers and operators from all over the world who have demonstrated a keen interest in the overall problem.

ACKNOWLEDGMENTS

The authors wish to call particular attention to the contribution of Mr. Torsten Stephanson, Director of the KaMeWa Propeller Laboratory under whose supervision the majority of the model testing was conducted. Also, the assistance of Mr. S. A. Jardmo and Messrs. H. C. Downer and Associates, Inc. is gratefully acknowledged. In addition, it should be noted that without the permission and encouragement of the authors' respective firms, this paper would not have been possible.

Special note is made of the fact that portions of this paper were presented by Mr. L. Pehrsson at the First Symposium on Ship Maneuverability, May, 1960, sponsored by the David Taylor Model Basin.

B. F. Goodrich

***Cutless* Bearings**

OIL RESISTING RUBBER

FOR PROPELLER SHAFTS

There is a size and type of Cutless Bearing for every powered boat or vessel. Soft rubber, water lubricated, Cutless Bearings out-wear all other bearing materials.

LUCIAN Q. MOFFITT INC.

AKRON 8, OHIO

Engineers and National Distributors

SPACE-CONTROL SIMULATORS

Three atomic controls evaluation simulators (ACES) will soon make Dallas the nation's space-on-earth center. The first ACES is a 12 ft long, 30 x 36 in., aluminum-tubing platform. It weighs 1350 lb; yet it literally floats on air. This simulator's only link with its ground base is a 4½-in. steel ball. A column of nitrogen, pressurized to 120 psi, keeps the ball afloat.

The Iron Age, August 10, 1961

SUPERCONDUCTOR

Under a research contract with the AEC, Atomics International has developed a new superconductor material which offers no resistance to appreciable quantities of electrical current.

The new material is a cold-worked alloy made of about three parts of niobium to one part of zirconium. The alloy is malleable and strong and can be made into wires, bars, strips, and other shapes without losing its superconducting properties. Its development makes possible superconducting magnets to replace conventional bulk and relatively inefficient ion-core electromagnets. Such magnets would have no iron core and would produce magnetic fields many times higher than conventional electromagnets.

Potential uses might be as high-energy particle accelerators or in space technology where the lightweight magnets could store more energy in less space than conventional electrical capacitors.

Mechanical Engineering, August 1961

COMBINATION PROPELLING MACHINERY IN NEW FRIGATES

The first of the new ***Tribal***-class frigates, H.M.S. ***Ashanti***, built by Yarrow and Co.,Ltd., recently completed contractor's sea trials, and features an interesting combination of both steam and gas turbine propelling machinery. This system was developed by the Yarrow-Admiralty Research Department and Associated Electrical Industries, Ltd., the fluid couplings and S.S.S. automatic clutches being designed and constructed by Fluidrive Engineering Co., Ltd.

The ship can be propelled, as desired, by steam or gas turbines or by both when boost power is required. A main S.S.S. synchronizing clutch automatically connects or disconnects the gas turbines with the steam turbine. Furthermore, when the ship is being propelled by the gas turbines alone, with the steam side disconnected, maneuvering ahead or astern is through the corresponding fluid coupling and appropriate gearing, a simple control filling or emptying either fluid coupling according to the direction required.

The Motor Ship, August 1961

"RESEARCH LABORATORY BULLETIN"

SUPERCONDUCTIVITY

ACKNOWLEDGMENT

This three part article is reprinted from the General Electric Company Research Laboratory Bulletin, Winter 1961 issue. Parts I and II were written by the staff of the Bulletin, Part III by Dr. Vernon L. Newhouse of the Research Laboratory.

PART I

ELECTRON TUNNELING BETWEEN SUPERCONDUCTORS

A MAJOR discovery that may yield vastly improved knowledge of both superconductivity and electron "tunneling" was revealed late in 1960, when it was announced that tunneling had been observed for the first time in devices consisting simply of two metal films separated by a thin insulating layer, with one or both of the metal films in the superconducting state. Previously tunneling had proved useful only in carefully prepared semiconducting devices.

In announcing the discovery, Dr. Guy Suits, vice president and director of research, said: "This discovery, made by Ivar Giaever of the GE Research Laboratory, is so recent that all of its consequences have not been fully determined. However, it is already adding to fundamental knowledge of both tunneling and superconductivity and has opened a new approach to the construction of versatile, microminiature electronic components. For example, it may be possible to make—in an entirely new way—a simple device that could function as a switch, diode, negative-resistance diode, triode, resistor or capacitor."

Until now, the only wide application of electron tunneling has been in the relatively new semiconducting tunnel diode. However, tunneling occurs in a broader class of materials than semiconductors. In Giaever's discovery, tunneling occurs through the simple barrier of an insulating film, rather than through the charge depletion region of a semiconductor p-n junction, as in the case of the tunnel diode.

The tunneling of electrons through thin insulating layers can be understood by thinking of the charge-carrying electrons not as particles, but as waves. When these charge-carrying waves strike a barrier (such as would be imposed by an insulator), virtually all of them will be reflected back from the

barrier. There is a certain small probability, however, that a portion of the waves will pass through the barrier if it is thin enough. If a conductor is present on the other side, the presence of these "tunneling" waves may be detected as current. Despite the small probability of waves "tunneling" rather than reflecting, a substantial current may flow simply because the number of waves is so large.

Certain conditions must prevail for electron tunneling to be significant. If two plates of metal are separated by a good insulator, they form a capacitor, or condenser. Current does not flow through the insulator, even if it is as thin as a ten-thousandth of an inch. However, if the insulator is made almost infinitesimally thin, say from 10 to 100 atoms thick, the probability of electrons getting through the barrier becomes sufficient for a measurable current to flow. At relatively low voltages, the current induced by tunneling is proportional to the voltage, just as it would be if the insulator were an ordinary resistance element.

Giaever's Experiment

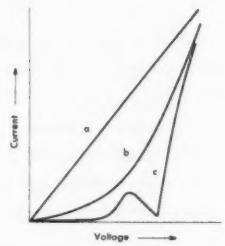
In experimenting with tunneling through such ultra-thin insulating films, Giaever found an unexpected effect when one of the conducting films was a superconductor. Instead of a straight line graph showing that the current increased proportionally with the voltage, a convex curve was produced, indicating that an effect similar to that in the tunnel diode might be involved. Giaever quickly followed up this lead and found that a region of "negative resistance"—in which the current decreases with increasing voltage—could be observed if *both* metal films were superconducting, (see accompanying graphs).

This effect is the result of the fact that certain energy levels in a superconductor are "forbidden" to electrons. Any electrons in one metal film that have energies equal to "forbidden" energies in the other metal film cannot tunnel through the intervening insulating film. Therefore these forbidden energy gaps in superconductors have a profound influence on the tunneling currents and lead to the unique behavior discovered by Giaever. Similar regions of negative resistance were previously observed only in tunnel diodes.

This unpredicted finding has important implications for theories about superconductivity and about tunneling. From the practical standpoint, the discovery may become important by making possible a new family of devices unequalled for their small size and versatility.

The negative resistance effect is unique in that it is independent of the direction in which the current flows through the device. This versatility is not possessed by the tunnel diode. In addition, the negative resistance region may be changed by subjecting the device to a magnetic field or by changing the temperature.

Small size of devices that could be made utilizing Giaver's discovery is indicated here. Operating portion of the device is the area where the two strips cross.



Tunneling through a thin insulating film: (a) tunneling between two normal metals; (b) tunneling between a normal metal and a superconductor; (c) tunneling between two superconductors.

Most of Giaever's experiments have been with films of aluminum, lead, indium, and tin, all of which becomes superconductive near liquid helium temperatures. A considerable number of other metals are expected to exhibit the same effect. In almost all of the experiments, aluminum oxide was the insulating layer, although Giaever has obtained proof of tunneling through tantalum oxide, niobium oxide, and nickel oxide as well.

One of the primary advantages of any device incorporating the effect discovered by Giaever is the possibility of changing the device's characteristics with a magnetic field (see Part II). By varying a magnetic field, one or both of the superconducting films can be changed to the normal state, with a consequent change in operating characteristics of the device. This is why it may be possible for the device to function as a switch, diode, negative-resistance diode, triode, resistor, or capacitor.

Other potential advantages of devices based on the new effect would be extremely small size, low power requirements, and cheapness of fabrication. Since the devices would be made simply by depositing metal and insulating films on a suitable substrate, it would be possible to deposit complex circuits involving hundreds of active components in one operation. This would result in a very large

reduction in cost from present methods of fabricating and assembling complex circuits, and would make possible a comparably large reduction in size. The extremely low power dissipation makes it possible to pack the microminiature elements at a density many times greater than is possible with present semiconductor components.

A great deal of applied research and development will be required to evolve practical devices based on this new concept. Also, the requirement of cryogenic temperatures for the suggested new components may be a handicap, but this is not expected to be too serious for many uses.

Scientific Importance

The discovery of these new, previously unsuspected effects is making an important contribution to fundamental scientific knowledge of both superconductivity and tunneling. One of the basic problems of superconductivity is why some materials are superconductors and others are not. The experiments Giaever has designed are contributing data that may prove useful in solving this problem. Moreover, solid state physicists now find it necessary to develop the theory of electron tunneling beyond the previous state of understanding—which was sufficient to explain tunnel diodes—in order to explain fully these new results. In addition to Ivar Giaever, other scientists of the General Electric Research Laboratory are actively engaged in this area of research, including Drs. John Fisher, Walter A. Harrison, Charles P. Bean, Vernon L. Newhouse, and Mr. Karl Megerle.

Part II

A NEW RESEARCH TECHNIQUE

The discovery of superconductivity nearly fifty years ago created a sensation in the world of physics. The fact that certain materials lost all electrical resistance at low temperatures was completely unexpected. The effect was a subject of prime interest to both theoreticians and experimentalists for many years. Altogether some 25 elements and more than 250 alloys and compounds have been found to be superconductors.

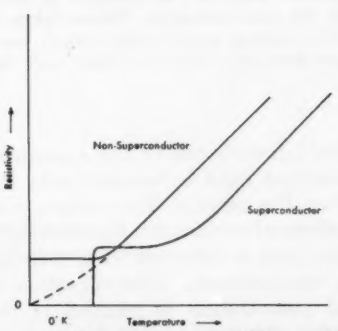
Activity in the field was restricted, however, because few laboratories were equipped to produce the low temperatures required, and because other fields of research were opened that seemed to offer greater promise.

As so frequently has happened with other discoveries in "pure" science, after a lapse of many years advances in technology have made important applications appear feasible, and superconductivity is now a subject of intense interest. The advances primarily responsible for this revival of interest are improvements in refrigeration techniques that make it relatively easy to operate devices continuously at temperatures a few degrees above absolute zero, and the need for gigantic arrays of switching and memory elements for electronic computers. (See Parts I and III) A new method of studying superconductors, developed at the Research Laboratory, is facilitating such applications as well as providing basic new knowledge.

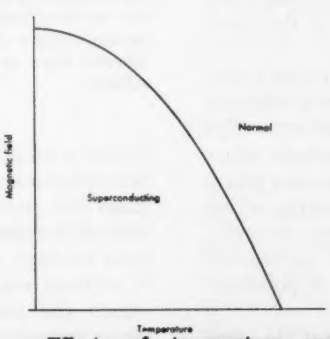
Effect of Temperature on Resistance

As shown in the accompanying graph, the resistance of most electrical conductors decreases as the temperature is lowered, until at around 10° K., it becomes independent of temperature. The minimum value is dependent on strains and impurities in the metal, and the resistance of a perfectly pure single crystal of the metal would become zero at 0° K., as shown by the dotted line.

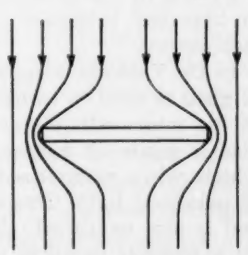
The behavior of superconducting materials is strikingly different. Their electrical resistance vanishes completely at a temperature called the critical temperature, which for most superconductors is below 10° K. The electrical resistance is not just small, it is exactly zero. Currents set in motion in loops of superconducting wire have been observed to continue undiminished for more than a year.



Change in resistivity with temperature.



Effects of temperature and magnetic field on a superconductor.



The diamagnetism of a superconductor excludes magnetic lines of force, leading to an increase in the field strength at the edges.

The magnetic behavior of a superconductor is as surprising as its electrical behavior, and is the basis for most of the likely applications. When a material is in the superconductive state, it is perfectly diamagnetic; that is, magnetic lines of force do not penetrate it. However, when the applied field reaches a certain critical value, the superconductor is changed to the normal state. The variation of the critical field with temperature for a superconducting metal is shown in the graph.

Thus a superconducting material can be changed to the normal state either by raising its temperature to a point above the critical temperature or by subjecting it to a magnetic field greater than the critical field.

If just the right magnetic field is applied, an "intermediate state" can be produced in which portions of the sample are normal and portions superconductive. The intermediate state arises from the diamagnetism of superconductors. If a transverse magnetic field is applied to a superconductor which has a relatively wide, thin cross section, magnetic lines of force will be bent sharply around it since they cannot penetrate, as shown in the drawing. This produces a closer spacing of lines of force or, in other words, a stronger field at the edges. At proper field strengths, the magnetic field at the edges will reach the critical field. The edges will then revert to the normal state while the center portion remains superconductive.

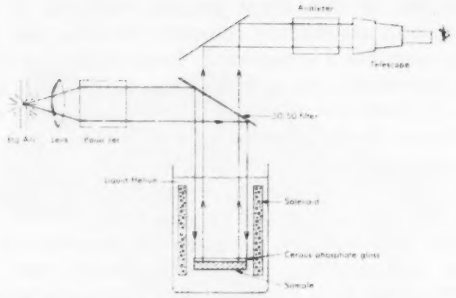
This intermediate state is of great scientific and practical interest. The manner in which it changes with variations in the magnetic field, and differences in the purity, geometry, and metallurgical treatment of the specimen are of great importance to electronic applications of superconductivity.

A New Research Technique

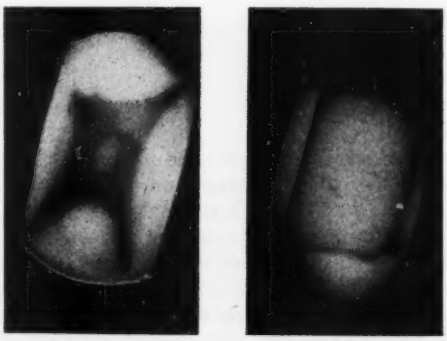
By combining the magnetic properties of superconductors with an ingenious optical system, Dr. Warren DeSorbo has developed a new method for studying the intermediate state which is yielding important new information. The technique permits direct visual observation of magnetic changes taking place in the specimen, and was developed from an approach originally tried at the Naval Research Laboratory.

In Dr. DeSorbo's apparatus, a thin (¼-mm.) disc of glass is used to translate the magnetic properties of the intermediate state into visible patterns. The disc is made of a special cerium phosphate glass which, when magnetized, strongly rotates the plane of polarized light. This is called the Faraday effect and is also exhibited, although much less strongly, by a number of other materials. When unmagnetized, the glass does not rotate the plane of polarization.

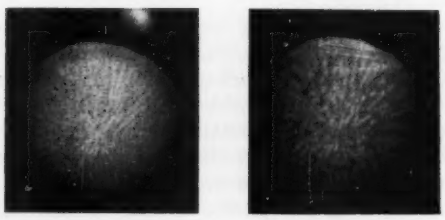
The disc of glass is placed on the sample, and both are cooled to a temperature of about 1.5° K. in liquid helium. A coil around the apparatus produces a magnetic field transverse to the specimen. Monochromatic, polarized light is beamed onto the glass disc mounted on the sample. The bottom surface of the glass is silvered so that the incident light goes through the glass and is reflected back through it without reaching the specimen. (The direction in which the plane of polarization is rotated is the same regardless of the direction in which the light is passing through, so the effect is doubled in light reflected back through the glass.) The reflected



Schematic diagram of apparatus developed by Dr. Warren DeSorbo to study the intermediate state in superconductors.



Non-equilibrium nature of the intermediate state is shown by these two photos of tin specimens at the same temperature and magnetic field. Pattern at left was produced by raising the magnetic field, the other by lowering it from a higher level.



Rapid movements of normal areas in a superconductor upon removal of a magnetic field can be followed in detail for the first time using the new technique. Photos taken 30 seconds apart show how normal areas (light color) move toward edge of tin specimen (in photo at right) and disappear.

light is observed through an adjustable polarizing filter, or "analyzer."

Since the glass is in close contact with the specimen, portions of it directly above superconductive portions of the specimen are shielded from magnetism, and do not rotate the plane of polarization. Portions of the sample in the normal state allow the magnetic field to penetrate the glass, and these portions of the glass do rotate the plane of polarization. By adjusting the viewing analyzer, the magnetized portions of the glass can be made to appear dark and the unmagnetized portions light, or vice versa. The dark and light areas of glass then corresopnd exactly to superconductive and normal areas at the sample's surface. The amount of rotation is proportional to the strength of the magnetic field, so quantitative measurements can also be made.

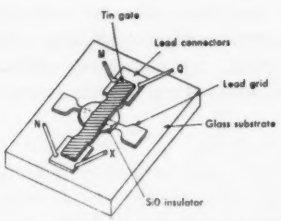
The special value of the new technique lies in its making possible the observation of dynamic aspects of the intermediate state, such as the movement of boundaries between normal and superconductive regions, and the "channels" through which normal areas penetrate superconducting regions. Details of these motions can be seen for the first time. The method has also permitted valuable studies to be made of effects of geometry and current flow in superconductive films. These studies are of particular value in design of such electronic devices as the crossed-film cryotron described below.

Among the results so far is the finding that the patterns of superconducting and normal areas are extremely complex, and that equilibrium conditions in the intermediate state have rarely, if ever, been obtained. Patterns at the same field strength and temperature are different when produced by raising, as compared with lowering, the field strength or temperature. Various approaches are currently being tried in an effort to obtain true equilibrium patterns. Such patterns may provide essential clues to better understanding of how materials transform between the superconductive and normal state.

Part III

THE CROSSED-FILM CRYOTRON

The word "cryotron" is used to describe any superconductive four-terminal device in which a magnetic field, produced by passing a current through two input terminals, controls the resistance between two output terminals. Such a device, using wires, appears to have been first developed for laboratory purposes in 1935 by Casimir-Jonker and de Haas. In 1956 the late D. A. Buck pointed out the possible advantages of such devices for the digital computers which had been developed in the intervening period, and suggested the name by which the device is now known. In the wire-wound cryotron shown in the drawing, a small current passed through the coil changes the superconducting "gate" wire to the normal state, increasing its resistance by such a large factor that it functions as a switch.



Schematic diagram of a crossed-film cryotron shows its extreme simplicity.

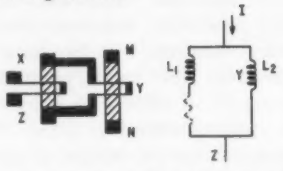
The author, together with John W. Bremer, several years ago began investigating the possibility of producing a cryotron of flat geometry, using metal and insulator films. Such a device, called the crossed-film cryotron (CFC), was successfully developed and shows considerable promise as a switch and memory unit for computers and other large-scale electronic devices. Harold H. Edwards has assisted in further development of the CFC, together with Hubert Tanis and Donald McKellar.

The general arrangement is shown in the drawing on this page. Current passed through the narrow lead film produces a magnetic field which is capable of causing the tin "gate" film to become resistive. The two conducting films are separated by an insulating film. Operation of the device is not sensitive to impurities in the films.

The CFC is operated in liquid helium at a temperature of about 3.6°K (−269°C). The temperature chosen is well below the critical temperature of lead and just below that of tin, so that only a relatively small magnetic field is required to change the latter to the normal state. The lead control and the lead interconnections between elements remain superconducting throughout.

A considerable increase in the operating speed of CFC circuits can be achieved by depositing them on an insulated superconductor or superconducting film so arranged that this film and the control are on opposite sides of the gate film. The speed is increased because the superconducting "ground plane," by preventing the penetration of any magnetic fields, considerably reduces the inductance of a conductor placed in its proximity.

CFC's as Memory Units



A cryotron storage cell and equivalent circuit. See text for explanation of how the cell can store information as an element in a computer.

The way a CFC functions as a switching or memory unit in a computer can be understood with the aid of the diagram above, which shows how the films are arranged and an equivalent circuit. If current is flowing between X and Z, most of it takes the path XZ rather than XYZ, because the former has much lower inductance. But when a current is passed through the input control, XZ becomes resistive and the current is diverted to path XYZ. It is an interesting property of superconducting circuits that, when the input control current is switched off, the current will continue to flow through XYZ even though XZ becomes superconducting again. While the current continues to flow through path XYZ, it makes path MN resistive, thus controlling the next element in the circuit. If now the external current is cut off, a circulating current will continue to flow in the loop XYZX indefinitely, since the entire loop is superconductive.

This circulating current can, of course, represent stored information, and the presence or absence of current in the element can be determined by testing path MN for resistance.

Application to Computers

The large improvements that crossed-film cryotrons may make in computer performance are due to their small size, potential simplicity of production, and low power dissipation. It is estimated that 18,000 CFC's can be deposited in one square foot, assuming that each element is fed by four controls. It appears that 60 such one-square-foot arrays might be stacked into a volume of one cubic foot, leaving ample space between them for heat dissipation. This would give a density of slightly more than one million cryotrons per cubic foot.

The heat dissipation of a typical CFC is less than 5 microwatts, so that a million of them, with each element excited on the average 10 per cent of the time, would have a total heat dissipation of less than one-half watt. Even the smallest conventional devices have individual dissipations of several milliwatts, so that adequate heat dissipation requires substantially lower packing density than with the cryotron. Small liquid helium refrigerators have been developed which would be able to keep an array of a million cryotrons at operating temperature.

The actual operation of a CFC is fast; there is no hysteresis and the transition from the superconducting to the resistive state in the gate film is very sharp. The switching time is only a fraction of a millimicrosecond—so fast it has not yet been measured accurately. However, the speed of operation of cryotrons is determined by the time constant of the circuit of which they are a part, which depends on the ratio of inductance to resistance in the circuit. It is usual to define this time constant as that of the circuit in which one CFC drives another similar one. The CFC's illustratetd have time constants of the order of 0.1 to 0.4 microseconds, depending on the gain used and the temperature of operation. As with other devices, the time constant can be reduced at the sacrifice of gain. For memory circuits, where gain is not required, time constants in the millimocresecond range have been demonstrated.

Computers of the Future

Present-day computers use vacuum tubes or semiconductor devices for amplification and switching, and magnetic cores for random access memories. Many problems exist which no present computer is fast enough or complex enough to solve. Some of these problems could be solved by either greatly increasing the speed of operation, or by using millions of switching and storage elements.

Production and assembly costs of computers using individual wired elements rise alarmingly as machine size and complexity grow, and machines having millions of switching elements would be prohibitively expensive. By making it simple to deposit large numbers of active electronic devices and their interconnections at one time, the CFC may well permit revolutionary advances in the capabilities of computers in the years ahead.

"MARINE ENGINEERING/LOG"

SHIPBUILDING COST CAN BE REDUCED

ACKNOWLEDGMENT

This article is a condensation prepared by the staff of "Marine Engineering/Log" of a paper by Paul E. Atkinson, Vice President of Sun Shipbuilding and Dry Dock Company. The paper was originally presented to the New York Section, Society of Naval Architects and Marine Engineers and the condensed version appeared in the May 1961 issue of "Marine Engineering/Log" from which it is reprinted.

THE DECLINE OVER the past 20 years of American-flag merchant vessels on the high seas should be a matter of serious concern to each of us in the marine industry. Obviously the reasons underlying this unwelcome state of affairs are economic. As the competitive squeeze has become more acute, the need for lower costs in all segments of our marine industry has become more apparent.

One of the substantial parts of American merchant marine costs is the capital cost which reflects the price of new vessels built in American shipyards.

Shipbuilding costs can be subdivided into the four fundamental elements of the ship's sales price, namely—material, labor, overhead and profit.

MATERIAL

This is by far the largest category and the one over which the shipbuilder has the least control. If substantial progress is to be made toward lower costs, this area must receive the principal attention. This material item might be composed of the following parts for a recent cargo vessel.

Mill Products — Plates, shapes, bars, pipe, forgings, sheet, electric cable, castings, fasteners and similar items .....$ 800,000
Manufactured Goods — Special — Turbines & gears, boilers, propeller, turbine generator sets, hatch covers, cargo gear, W.T. doors, lifeboats, airports, evaporator, navigating equipment, anchor gear, and other similar items peculiar to the marine business $3,000,000
Manufactured Goods—Normal—Valves, flanges, pumps, motors, fans, controls, fittings, electric fixtures, and similar items more closely allied with construction ashore $1,000,000
Services — Insurance, bonds, fees, dry-docking, subcontractors, tug-boats, model tests and other similar services $700,000

The mill products are purchased at published prices and it does not appear, at least at the moment, that much will be done to reduce the unit prices for these items. The principal avenue for improvement must lie in minimizing quantities purchased and extras specified. The predominant extra in shipbuilding is the quality extra on plates al-

though the shape extras are becoming substantial, particularly on specialty items. Freight costs also must be carefully considered due to the large quantities involved.

Figure 1 shows the delivered price of steel plates and shapes at Chester, Pa. over the past several years. The base price of steel also is indicated. The divergence between the base price and delivered price reflects essentially the increased extras charged by the mills. Actual freight costs have varied ±15 per cent from the 1950 base. Today as a result of using truck shipment, these rates are down about 10 per cent.

We should bear in mind that the order of importance of this mill products category in the whole increases two or threefold when one considers tankers or bulk carriers rather than the cargo vessel under discussion. These mill products also form a part of the two manufactured goods categories. The author estimates this might amount to an additional $200,000.

The two "manufactured goods" categories indicated are really difficult to separate since special marine requirements tend to creep into the second group. The division into the two groups is intentional, however, since great cost reduction potential exists in reducing our special marine requirements to a more functional, reasonable and standard set of specifications.

The "services" category is substantial. Many of the items involved do not contribute tangibly to the final product. A few of the items listed are not subject to competitive pressures. The subcontracting portion can vary greatly from yard to yard.

LABOR COSTS

Labor costs in shipbuilding are dependent on two things, the number of man-hours of work required to build the ship and the average earned hourly rate. Shipyard labor in the U.S. is in general highly organized and affiliated with powerful national labor unions. Wage patterns over the past several years have been set by one or another of the large unions and the industry has generally fallen in line with these patterns. Although the pace of these increases has slowed some in the past year, there is no tangible reason to believe that shipbuilding wages will not continue to advance along with other similar industries as the years go by.

Figure 2 shows the Atlantic Coast shipbuilding labor index of hourly earnings for the past 20 years.

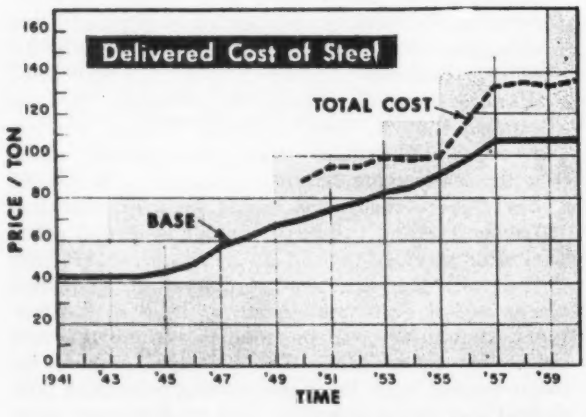
OVERHEAD CHARGES

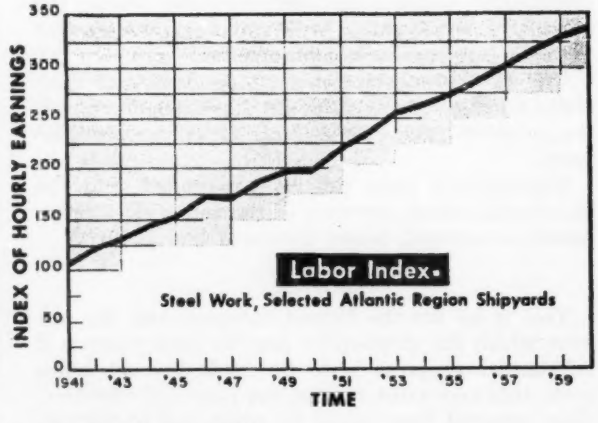
Shipyard overhead charges are composed essentially of costs which cannot be charged directly against a specific ship or job. They are consequently collected and periodically allocated to the various jobs in process on the most reasonable basis the accountants can derive. These charges cover essentially:

1. *Maintenance* and repairs to plant and equipment.
2. *Wages and salaries* not directly chargeable to a specific job—for example, toolroom attendants, storm labor, janitorial services, accounting, supervision, power plant operators, etc.
3. *Fringe Benefits*—Includes vacations, paid holidays, unemployment insurance, group life and hospitalization insurance, etc. This is the most substantial item of overhead by a considerable margin.
4. *Utilities and Supplies*—Electricity, fuel, water, gas, oxygen, welding and cutting supplies, lubricants, etc.
5. *Miscellaneous* items including taxes, insurance, depreciation, administrative expense, interest and rental charges, etc.

Overhead costs are usually allocated monthly on the basis of direct labor expended against each job. Consequently, overhead costs per ship are dependent, among other things, on the volume of direct labor expended in the entire shipyard.

In the long run consideration of the ship-cost-





Figures 1 and 2. Indices of key shipbuilding cost factors.

reduction problem, depreciation as a part of overhead deserves special mention. The shipbuilding industry is faced with rising costs in replacing and modernizing its plant. Present depreciation practices are not adequate in the writer's opinion to allow the industry to properly modernize its facilities.

PROFIT MARGIN

Shipbuilding is first, foremost and fundamentally a business, and consequently the management of a shipbuilding firm is subject to the same influences which exist in every business. Customers, employees, suppliers, stockholders and the community in which the business operates, are important factors which must be considered in every company. A business enterprise cannot long exist without profits. It will not thrive without substantial profits to reinvest in better facilities. This is true of the shipbuilding business.

An examination of the financial statements of the major shipbuilding companies over the past few years will indicate that profit margins are not excessive.

AREAS FOR ACTION

One of the most serious problems facing us in establishing a sustained fruitful cost reduction program is group apathy. If a substantial number of the shipowners, designers and builders decide that this problem is really important, then tremendous strides can be made. If not, no progress is likely.

Further, Owners and the Government must recognize that the design and construction of an ocean going vessel is a task best solved through joint and cooperative efforts with the shipbuilder. Interest in cost reduction prior to bid openings must be sustained through the long design and construction period.

Assuming this favorable environment, the basic areas involved must be approached one by one and a program for action in each area established. The author has set forth the problem areas as he sees them, the reasons for their importance and a program for action in each case.

1. *Paper Work*—The application of judgment and reason to present administrative requirements will reduce costs substantially. Present requirements defy belief.

a. Drawing-office practice has reached the point where it is dictated by administrative procedures rather than construction requirements. Inspection procedures and requirements have become ponderous. No effort has been made to establish only those procedures needed to assure the construction of a serviceable vessel. The author's company has built large vessels where approval by the owners was required twice; once at the plan-approval stage and once on acceptance. Under these conditions regulatory-body problems also tend to be minimized. These vessels have been successful and less expensive than their highly approved cousins.

b. The owner is interested in the vital construction plans for the vessel. Little useful purpose is served by submitting for approval the remaining 70-80 per cent of the working plans, or in issuing these plans and all subsequent alterations to all hands. The same reasoning should apply to material requisitions.

c. There is no real need for many of the vendors plans and instruction books now required.

d. Allowance lists, test reports, progress reports, and other miscellaneous items do not contribute to the operation of the vessel. Serious question as to their worth in their present form can be raised. For the allowance list for example, every one of the 500-odd pages is separately submitted for approval.

e. Although adequate testing is essential, the present testing procedures for vessels in the replacement program are cumbersome and overconservative.

Program for Action

1. Resist all efforts to add to present paper work.

2. Drastically revise administrative procedures to include only vital requirements. Retain the fundamental requirement that the shipyard provide a suitable vessel subject to a guarantee of 6 months' of normal operation.

3. Sharply reduce the number of plans and material requisitions required to be approved. Reduce the distribution list for this data.

4. Eliminate overlapping requirements of regulatory bodies.

5. Re-assess actual needs on instruction books, allowance lists, test reports and similar items. At least half of the present requirements can be eliminated.

6. Streamline existing Maritime Administration test procedure, particularly the electrical portions.

7. Reduce inspection staffs to more reasonable proportions. Use crew to supplement test staff as required.

PLANS AND SPECIFICATIONS

Specifications for a pre-war vessel contained about 150 small pages. They were concise and complete. Today, specifications generally are at least ten times as large and in general less effective.

The "best" material is not required in many applications. The test of material should be its adequacy, not its superiority.

Due to administrative problems, particularly delay, no incentive exists to change existing specifications to incorporate new or alternate ideas or methods.

Overspecifying of details of material and methods of construction is common in the industry today.

Program for Action

1. Eliminate all extraneous language presently incorporated in specifications. Spell out functional requirements, not the method of manufacture.

2. Specification limitations on shipyard methods should be carefully reviewed and deleted where restrictive unless sound reasons exist therefor.

3. Ease administrative restrictions surrounding changes in specifications. Encourage "give and take" relationship and discourage legal and literal interpretations of specifications.

4. Broaden and relax contract documents along same lines.

AMERICAN "STANDARDS" OF CONSTRUCTION

Vessels built to American "standards" will cost significantly more than vessels built only to American requirements. There are real additional costs in building to American requirements. Initial cost is higher for fire proof construction, certain sanitary requirements, additional fire fighting installations, etc.

The additional cost of building to American "standards" is far more difficult to justify. In fact these "standards" themselves tend to be difficult to justify. Consider the following examples:

On recent subsidized cargo vessel designs on which bids have been received in the last 3 years, the stores reefer space has been divided into 4, 5, 6 and even 7 compartments. The compartments tend to be cut up or rectangular rather than square.

On the other hand, recent American-built U.S. and foreign-flag tankers generally have two compartments, much more nearly square.

The author estimates that the two walk-in boxes, typical of tankers, will be about $20,000 less expensive than the five walk-in boxes of the same capacity and that the reach-in installation will be about $20,000 less expensive than the two walk-in box job.

2. On every recent subsidized cargo vessel design on which bids have been received in the last 3 years, the turbogenerators have been specified as closed machines requiring special salt-water coolers for forced air cooling. Many of these machines have also been specified with a 25 per cent overload requirement for hours. This overload rating inherently requires the entire steam end including the condenser, etc., to be designed at 125 per cent of rated capacity. The generator end design is predicated on a certain allowable heat rise in a 2 hour time limit and presumably cannot be operated continuously at this rating. This 2 hour concept bears no relation to actual ship service requirements.

For years many U. S. and foreign built vessels have been equipped with open drip-proof machines at a saving of about $25,000 per ship. Maintenance costs are not excessive. Furthermore sizing the machines based on continuous operation of both steam and electric end at the same rating will usually save $10,000-$15,000.

3. On recent subsidized cargo vessel designs on which bids have been taken in the last 3 years, ventilation ductwork has been required to be fitted with flanges, presumably to facilitate the removal problem. This of course makes every piece of ductwork a "custom made" item which must fit accurately at both ends.

For years many other U. S. and foreign vessels and home-heating systems have used ordinary slip joints in ductwork joints at a substantial initial cost saving. The advantages claimed for bolted ductwork during the life of the vessel are more theoretical than practical and are far outweighed by the initial cost.

Program for Action

1. Critically examine these so-called American "standards" to determine the essential nature of each. Eliminate those not contributing to safety and performance of vessel.

DESIGN CHANGES DURING CONSTRUCTION

Changes during the design and construction stage disrupt schedules beyond reasonable appreciation. The cost of a design change is extremely high, particularly during the construction stage, sometimes resulting in the over-all cost of the work being several times its normal cost. Neither the shipyard nor the owner is usually satisfied with the final settlement. The remedy:

1. Eliminate changes during design and construction.

2. Consider revising contract form to eliminate owners right to change without prior mutual agreement.

STANDARDIZATION OF VESSELS

Custom-built vessels and components contribute materially to high costs. Impressive savings can be realized through standardization.

a. On duplicate ships or components, design and drawings, templates, patterns, jigs and fixtures and other development and set up costs can be spread over more units reducing cost per unit.

b. The learning curves of all concerned are interrupted with even minor changes in specifications thus creating unnecessary costs.

c. Design simplification and product improvement will result from focusing attention repeatedly on the same item.

d. Standardized vessels and components will reduce to a marked extent costly time pressure on delivery. The building task becomes much more orderly and manageable when the design problems are eliminated.

Program for Action

1. Reduce drastically the large number of designs under construction. The custom-built vessel cannot be built at a competitive price.

2. Insist on standard components.

3. Modify the standard vessels to a minor degree after delivery to each owner, if necessary.

COMPETITION

Competition is undoubtedly a most effective factor in reducing costs. Our economic philosophy has been based on this premise. Healthy competition invites innovation, initiative, invention and hard work. Prices are highest in those areas where competition does not exist. Ruinous competition and prices below cost will not produce long run economies for our industry.

Program for Action

1. Encourage all forms of healthy competition.
2. In those areas where one supplier dominates the field, nurture those others who can compete so that every area of the industry will eventually gain the benefits of healthy competition.

SHIPYARD WORKLOAD

Steady and continuing workload for shipyards is a prerequisite to important cost reduction.

a. The strength and ability of any organization will vary directly with the caliber of people it can attract. Capable people are not attracted to ephemeral enterprises.

Program for Action

1. Anticipate fleet replacement or new building requirements well ahead and carry through an orderly long range program despite minor fluctuations in the economic climate.
2. Adjust major ship repair and conversion activity to complement new building programs.
3. Increase diversification in shipyards.

SHIPYARD PROBLEMS

Many factors in the high cost of ships in this country are traceable to the shipyards. Methods and tooling are generally behind those existing in other American industries. The industry has not been noted for progressive thinking. Information has been closely held. Money spent for research and development has been minor. In general, plant and equipment in American yards is old and obsolete. Attitude has generally been a negative one, encouraging subsidy and Government support.

Program for Action

1. Modernize management methods.
2. Liberalize depreciation allowances to allow orderly replacement of plant and equipment.
3. Recognize importance and inevitability of competing in the world market.
4. Encourage interchange of information for good of entire industry.
5. Channel research funds to this cost problem.

The foregoing concepts and opinions involve complex, and, in some cases, controversial subject matter. To obtain tangible results on these items requires concerted action on a broad basis by a lot of people. Our success in reducing costs across the board will be proportional to the vigor with which we attack the problems.

FERTILE FUTURE FIELDS

Our merchant marine industry has been accused of arch conservatism, horse and buggy thinking and lack of initiative and enterprise. A sound case can be argued along these lines.

Pressure has been building up to alter this situation.

Consider the following areas for improvement. The rewards are great.

DEVELOPMENT OF LIGHTER, MORE ECONOMICAL STRUCTURES

Aircraft-skin thicknesses are measured in thousandths of an inch. Stiffening is far closer together than in marine structures. Experiments with aluminum structures in this general direction have been very interesting. The development of thin gauge pressed steel structures utilizing perhaps spot welded stiffeners and baked enamel finishes would certainly seem to be possible but have not even been explored. Much can be done to lighten present structures, particularly the deck houses.

WORKING DRAWINGS

The use of large scale engine room models together with color coding of piping systems and photography techniques available today may make engine room drawings obsolete. Approvals by regulatory bodies could be obtained through use of diagrams, material bills and visits to the actual model. The use of the model on the job to assist in actual fabrication and assembly operations is certainly worth considering.

COMPUTER APPLICATIONS

The next step from present day lofting practice is obviously computer control of flame cutting machines. This step presently awaits practicable development of mathematical lines, shell development and satisfactory template-making procedures.

The use of computers in the engine room space allocation problem and the consequent possibility of optimizing piping runs, eliminating interferences, developing detailed piping and miscellaneous requirements is interesting, to say the least.

ENGINE-ROOM MACHINERY

Reduction in the number of engine room units required will most effectively reduce costs.

A common rail system for salt water service could conceivably reduce the number of salt water pumps on a modern cargo vessel by at least half.

The use of standby prime movers for alternate purposes might affect substantial savings. For example,—if we could drive reefer compressors with the turbine of the standby turbo generator utilizing

a satisfactory declutching device, we could reduce the size of the generators themselves, eliminate breakers, wiring, reefer drive motors, controls, etc.

ELECTRICAL SYSTEM

Public utilities would not dream of operating their services at 0.8 power factor. In our business we design every current carrying item in our ships 25 per cent oversize as a result of operation at .80 power factor. Improvement here is overdue.

FUEL

The use of No. 6 oil involves serious tank cleaning and boiler slagging problems. These undesirable characteristics of No. 6 oil forecast its eventual elimination from the marine industry and replacement perhaps with gas.

The author has indicated several areas where improvements are possible and necessary. Many other areas are ripe for development. Progress has been untenably slow. Too much of our research effort has been of the longhaired variety. At a time when our industry is being seriously challenged by competitive modes of transportation, we are being hampered by the shackles of our own conservatism. Only through a real exhibition of the traditional American traits of initiative, enterprise, invention and daring can we hope to beat back these challenges to our very existence.

NEW WATER TUNNEL FOR PROPELLER AND HYDROFOIL TESTING

The Ship Hydrodynamics Laboratory of the National Physical Laboratory has recently put into service a new water tunnel, one of the largest in the world, for research work on propeller models up to 24 in. in diameter and for testing hydrofoils. The complete circuit is more than 500 ft. in length and has a water velocity through the test section of up to 50 f.p.s.; water pressures of 0 to 6 atmospheres can be accurately maintained.

The full circuit takes the form of a rectangle of steel tube, coated internally to reduce skin friction, in the vertical plane with the vertical sides some 180 ft. in length, largely below the ground, joined by 87 ft. long horizontal legs. The circuit, in general, has a diameter of 10 ft. while the test section, in the upper horizontal limb, has a length of only some 7 ft. and a restricted diameter of 44 in.

The large bore of the main body of the circuit is necessary to ensure the complete reabsorption of any air bubbles created by turbulence along the test length. Air bubbles produced in cavitation studies, in particular, are difficult to bring back into solution and such reabsorption is vital before the water repasses through the test section. The slower flow and reduced wall friction and turbulence in the 10 ft. circuit combine with the increased pressure on the air bubbles, induced by the 180 ft. depth, to ensure a 'clean' flow of water through the test section.

Circulation of water in the tunnel is effected by a 92 in. diameter axial flow impeller located about 35 ft. down on the down limb of the circuit—where there is a sufficient head of water to prevent cavitation. A variable speed drive from electric motors having a maximum continuous rating of 1,052 h.p. is provided, and the impeller blade pitch can be adjusted, between runs, to obtain optimum pumping characteristics over a variety of conditions.

Model propellers under test are carried on a long downstream shaft, driven by a 300 h.p. motor, running in the test section.

The circuit is pressurized initially, and pressure maintained during tests, by a Megator GH4 type pump set. This pump operates on a continuous recirculation through a small subsidiary tank, a by-pass valve permitting a proportion of the flow to be introduced or withdrawn from the main circuit. A servo system, connected with the monitoring instruments in the test section, regulates the by-pass valve and maintains the tunnel pressure within fine limits.

Shipbuilding Equipment, August 1961

A.S.N.E. LOCAL CHAPTERS

Ground Rules for Establishing Local Chapters.

In accordance with the By-Laws of the Society, the Council has set forth the following rules to govern the establishment of a local chapter:

"a) Twenty or more regular members, Naval or Civilian, may apply for a charter as a local chapter.

b) Each application must be accompanied by a list of members and a copy of local By-Laws. The latter must meet the following minimum requirements:

1. All financial dealings of the local chapter must be independent of the Society and can in no way obligate the Society as a whole. The local chapter shall be set up on a non-profit basis. All accounting shall be local.
2. Each active local Chapter shall receive from the Society a grant of $0.50 per year for each naval member, civil member, associate member, junior member or student member who resides in the local area and who associates himself with the local chapter.
3. Any technical papers presented at local chapter meetings, shall be submitted to the Secretary-Treasurer of the Society for consideration for publication in the JOURNAL. Any paper accepted will be paid for at regular rates.
4. Each local chapter shall submit a quarterly report of its activities to the Secretary-Treasurer. These reports must reach Washington, D.C. prior to 15 January, 15 April, 15 July and 15 October. This report shall contain a list of active local members as of the first day of the quarter for the purpose of computing the annual grant.
5. Associate, Junior and Student members of the Society shall be eligible for membership in a local chapter, entitled to all the privileges of other members except voting for and holding office in the Parent Society. The Council affirms the right of the Executive Committee of any local chapter to exclude any applicant for membership in the local chapter regardless of the status of the applicant's membership in the Society.

The local chapters of the Society are:

Chapter number 1	Flagship Section-Baltimore-Washington-Annapolis, Area
Formation being discussed	New York, New York
Initial interest reported	Houston, Texas Honolulu, T.H.

ACTIVITIES OF LOCAL CHAPTERS are reported on the following page.

CHAPTER NUMBER ONE

THE FLAGSHIP SECTION

Baltimore and Annapolis, Maryland-Washington, D.C. Area
Charter granted 28 April 1961
Officers:
Chairman: Mr. Uriah L. Allen, Jr.
Vice Chairman: Mr. Frank J. Smollen
Secretary: Mr. Herbert F. Hathaway
Treasurer: Mr. Rupert A. Blue
Councilors:
3 year term: Rear Admiral C.M.E. Hoffman, USN (Ret)
2 year term: Mr. Irving G. Herman
1 year term: Captain Vernon E. Day, USCG
Address: The Secretary Flagship Section, ASNE
Mr. H. F. Hathaway
c/o General Electric Co.
111 Park Avenue
Baltimore 1, Maryland

ACTIVITY

The Executive Committee held a meeting on 29 August 1961. In attendance were Allen, Blue, Day, Hathaway and Hoffman plus Committee Chairman: Ciaramaglia, Elliott and Glenn.

Plans for the initial technical meeting were firmed up as announced below.

The date for the following technical meeting was set as 5 December 1961 with details as described below.

Other business was disposed of.

The Section held its first technical meeting on 3 October 1961 at the U.S. Coast Guard Yard at Curtis Bay, Maryland. Sixteen members with eleven guests and about 18 persons associated with the yard as guests of the host, Captain Day, Commanding Officer of the Yard, attended.

Following dinner and exceptional social amenities provided by Captain Day, the group heard the first Society-sponsored technical talk entitled "Exotic Power Sources" by Commander Joe W. Thornbury, USN, Bureau of Ships, Navy Department. This paper is printed in this JOURNAL on page 647.

Lieutenant Commander O'Connell, introduced by Captain Day, described the thermo generator which the Coast Guard is developing. He pointed out that whereas Commander Thornbury's talk indicated primary interest in the development of large blocks of power, the Coast Guard's interest is in power in the order of 5 watts.

The talk was followed by discussion and a tour of the yard. Among other things, the 5 watt thermo generator which the Coast Guard is developing for buoy lighting, and glass cloth and epoxy boat construction were seen.

FLAGSHIP SECTION TECHNICAL MEETING

The second technical meeting of the Flagship Section will be held on 5 December 1961 at 8:00 p.m. at the Potomac Electric Power Company Auditorium, 10th and E Streets, N.W., Washington, D. C. The speaker of the evening will be

Dr. Gene Strull,

Manager Solid State Advanced Development Laboratory, Westinghouse Air Arm Division, Baptimore, Md. Dr. Strull's topic will be

"Molecular Electronics"

CHANGES IN MEMBERSHIP

The Society announces with pleasure that the following have joined its ranks since the publication of the August 1961 issue of the Journal.

NAVAL

Buttermore, Jack Earl, LT, USCG
U. S. Coast Guard Yard
Baltimore 26, Maryland

Hirsch, Robert Allan, LTJG, USNR
Marine Enginer, U. S. Maritime Admin.
Mail: 1865 University Avenue, Bronx 53, N. Y.

Horsley, Frederic Eugene, CWO -W3, USN (Ret.)
Mail: 9243 Marlow Avenue
Norfolk 3, Virginia

Ireland, Richard James, LTJG, USNR
John I. Thompson Co., Washington, D. C.
Mail: 3210 19th Street, North, Arlington, Va.

Ludwig, Marlin Clifford, CAPT, USNR
Vice President, Equitable Equipment Co., Inc.
Mail: 34 Versailles Blvd., New Orleans 25, La.

Nolte, George H., CAPT, USNR
Military Sales Engineer, Pratt & Whitney Aircraft
Mail: 43 Race Brook Road, West Hartford 7, Conn.

Ottone, Richard Michael, LTJG, USN
Marine Engineer
Mail: 81 Yale Street, Williston Park, L. I., N. Y.

Sherwin, Sidney Allyn, Jr., CAPT, USN
Head, Electronics-Electrical Design Branch
Bureau of Ships, Navy Department
Mail: 5800 Durbin Road, Bethesda 14, Md.

Trainor, Eugene F., LT, USCGR-R
Senior Engineer, Shipbuilding Div., Bethlehem Steel Co.
Mail: 11 Strawberry Lane, Scituate, Mass.

CIVIL

Behr, Joseph Louis
Chief Engineer, Vickers, Inc., Electric Products Division
1815 Locust Street, St. Louis 3, Mo.

Brown, Elisha Albert
Master - Shipfitter
Mail: 607 Brian Street, Baltimore 25, Md.

Chenowith, Franklin Henry
Foreman Machinist, USCG Yard
Mail: Box 240-B, Pasadena #1, AA Co., Md.

Crook, Richard Francis
Design Engineer, Westinghouse AirArm Division, Hydraulic Group
Mail: Route 2, Box 610, Severna Park, Md.

Curry, Charles Caleb
Sales Engineer, Commercial Engineering Co.
1627 K Street, N.W., Washington 6, D. C.

Dougherty, James Robert
Chief Engineer, Maryland Shipbuilding and Dry Dock Co.
Mail: 517 Overbrook Road, Baltimore 12, Md.

High, Martin Alvin
Master Machinist, U. S. Coast Guard Yard
Baltimore 26, Md.

Mustard, James A., Jr.
Asst. to the V. P.—Marketing, Exide Industrial Marketing Div.
The Electric Storage Battery Co.
Mail: Box 5723, Philadelphia 20, Pa.

ASSOCIATE

Cerar, Peter V.
Regional Director, Marketing
American Bosch Arma Corp.
Mail: 11 Thea Lane, Huntington, N. Y.

Dews, Gary Paul
Marine Engineer, San Francisco Naval Shipyard
Mail: 2620 Laguna Street, Apt. #3, San Francisco 23, Calif.

Lopes, Lino Antunes, First LT, Portuguese Navy
Chief Engineer, Hydrography Mission of Angola & S. Tome
Mail: N.R.P. Carvalho Araujo, Luanda, Angola, Portugal

Marshall, Don Murray
President, Bogue Electric Mfg. Co.
52 Iowa Avenue, Paterson, N. J.

STUDENT

Carabine, Brian Patrick
1964 Class, Manhattan College Engineering Dept.
Sebonac Road, Southampton, N. Y.

Lampell, Lloyd F.
Pratt Institute, School of Engineering
Part-time employment: N. Y. Naval Shipyard
Mail: 138-33 232 Street, Laurelton 13, N. Y.

Piersall, Richard F., MIDN, 4/C
State University of New York Maritime College
New York 65, N. Y.

Vaudreuil, Wilfred Joseph, Jr.
1963 Class, Duke University
Box 4668, Duke Station, Durham, N. C.

JUNIOR

Eckels, Donald Erdmann, LT, USN
Box 1711, USNPS
Monterey, Calif.

REINSTATED

Adair, James MacCracken Civil

Campbell, John F. ..... Naval

Gill, Percy O., LT, USNR ..... Naval

Smyth, Joseph H. Civil

RESIGNATIONS

Babcock, Hugh H. Civil

Graninger, Howard J. ..... Associate

Harris, Dale S. ..... Naval

Laube, Clarence Edward, LT, USN ..... Naval

Mott, Brock, LT, USNR ..... Naval

Murphy, James F. Civil

Petroff, Christopher C., LCDR, USN ..... Naval

DEATHS

It is with deep regret that we announce that since the last Journal we have received notice of the deaths of the following members:

Baker, W. R. G. Civil

Boys, Milburn G., CDR, USNR ..... Naval

Campbell, Perry B. Civil

Ferris, Raymond W. Civil

Haas, Albert F. Civil

Jennings, Howard L., LCDR, USN(Ret.) ... Naval

MacDonald, William A. Civil

Index to Advertisers

Advertisers Name	*Post Office Address*	*Page*
The Babcock & Wilcox Co.	161 E. 42nd Street, New York 17, N.Y.	690-1
Bath Iron Works	Bath, Maine	642
Bethlehem Steel Co.	25 Broadway, New York, N.Y.	680
Bird-Johnson Co.	21 West Street, New York 2, N.Y.	641
Buffalo Forge Co.	490 Broadway, Buffalo 5, N.Y.	692
G. O. Carlson	160 Marshalton Road, Thorndale, Pa.	741
Combustion Engineering	200 Madison Avenue, New York, N.Y.	718
DeLaval Steam Turbine Co.	Nottingham Way, Trenton 2, N.J.	726
Dorn Equipment Co.	27 Upham St., Melrose 76, Mass.	725
Gibbs & Cox, Inc.	1 Broadway, New York, N.Y.	679
J. J. Henry Co., Inc.	21 West Street, New York 16, N.Y.	707
Johns-Manville Corp.	Box 290, New York 16, N.Y.	688
Kingsbury Machine Works, Inc.	Frankford, Philadelphia 24, Penna.	653
Leslie Co.	709 Grant Avenue, Lyndhurst, N.J.	664
Lucian Q. Moffitt, Inc.	Akron, Ohio	795
National Broach and Machine Co.	5600 St. Jean, Detroit 13, Mich.	762
Newport News Shipbldg. & D.D. Co.	Newport News, Virginia	684
R.C.A., Defense Elec. Div.	Camden, New Jersey	689
Rosenblatt & Son	350 Broadway, New York, N.Y.	761
Solar Aircraft Co.	San Diego 12, Calif.	714
Terry Steam Turbine	Hartford, Conn.	771
Westinghouse	3 Gateway Center, Pittsburgh 30, Penna.	742-3
C. H. Wheeler/Griscom-Russell	Philadelphia 32, Penna.	708
Whittelsey, H. Newton	17 Battery Place, New York 4, N.Y.	761

BOOKS RECEIVED

"Metallic Fatigue" by W. J. Harris. A broad survey of the major factors which affect the fatigue behavior of metals. Included is a survey of testing machines and apparatus as well as full consideration of theoretical treatments. Published by Pergamon Press, Inc., 122 East 55th Street, New York 22, New York. 331 pages, $12.50.

"Stress Concentrations Around Holes" by G. N. Savin. This book deals thoroughly with the problem of stresses set up around holes of various shapes in beams and plates subject to different kinds of loading. Professor J. N. Goodier, in a review, stated that this is one of the six most important books on elasticity published in the last decade. Published by Pergamon Press, Inc., 122 East 55th Street, New York 22, New York. 430 pages, $15.00.

"The Theory of Lebesgue Measure and Integration" by Stanistaw Hartman and Jan Mikusinski. A brief text on the theory of Lebesgue measure and integration simplified so that a background in elementary calculus is sufficient for understanding. Published by Pergamon Press, Inc., 122 East 55th Street, New York 22, New York. 176 pages, $5.00.

"Transactions of The Royal Institution of Naval Architects" Volume 102, 1960, edited by Captain A. D. Duckworth, R. N., secretary of the institution. Published by the Royal Institution of Naval Architects 10, Upper Belgrave Street, London, S. W. 1, England. 715 pages.

PAPER REVIEW

The Hydrodynamical Performance of Migratory Salmon

by M. F. M. Osborne
U.S. Naval Research Laboratory

The Navy has engaged in research in marine biology for many years without general acceptance of the pertinence of such investigations to naval architecture and engineering. The paper here mentioned is one outcome of this research. It was published in the Journal of Experimental Biology in Great Britain in 1961; Volume 38, pages 365-390. The paper is too long for reproduction here but the following summary, reprinted from it indicates the possible pertinence to subjects of specific interest to readers of this JOURNAL.

SUMMARY

The annual spawning migration of Pacific Coast salmon up the Columbia and Amur rivers has been analysed as an experiment on the maximum range of an unrefuelled vehicle, since the fish do not eat during this migration. The fuel (primarily fat) available to real fish is compared to that computed for an equivalent rigid vehicle with the following performance specifications which may be regarded as optimum ones for marine vehicles.

1. A choice for the speed of ascent against the average river current corresponding to the least fuel consumption, without seeking systematically either low- or high- velocity water.

2. A drag coefficient corresponding to a turbulent boundary layer with no separation.

3. An overall efficiency of 23 percent for converting the heat of combustion of the fuel to directed kinetic energy in the wake. Under these assumptions, the vehicles usually require slightly more fuel than the corresponding fish which they are intended to approximate; in the case of blueback salmon, the vehicle requires about five times as much. One, therefore, concludes that the fish have a performance superior to that of the best engineered rigid vehicles, as defined and operated under the above three specifications. Suggested explanations for the apparently superior performance of the fish are:

(1) a deliberate seeking, by the fish, of low-velocity water close to the bottom or shoreline;

(2) the ability of the fish to maintain a laminar rather than turbulent boundary layer;

(3) the ability of the fish to extract energy from the turbulent velocity fluctuations of the river.

Analysis of salmon counts over the Bonneville and Rock Island dams on the Columbia River shows that the average velocity of the fish upstream is influenced by the velocity of the water downstream in the following peculiar fashion, depending upon whether one considers water-velocity variations through the course of a year, or variations at a fixed season of the year, from one year to the next. The general effect of the water velocity as it varies through a year, is to slow the fish down when the water velocity is large (at the June flood peak) and to permit faster ascent when the water velocity is less, in both preceding and following months. But at a fixed season of the year, prior to the flood peak in June, relatively high-velocity water slows them down. These relationships are in agreement with other biological observations and with an analysis of navigation for minimum fuel consumption.

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

ASSOCIATION NOTES

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

COPIES OF JOURNALS

The Society has made arrangements with the Johnson Reprint Corp. to be our sole representative for the sale of copies or reproductions of any Journals or parts of Journals which were printed prior to 1951. Any requests or inquiries which are received by the Society for these will be forwarded without any action by us.

When making inquiries as to the procurement of or orders for copies or portions of any Journal from Volume 1 (1889) through Volume 62 (1950) please address

Johnson Reprint Corp.
111 5th Avenue, New York, N.Y.

For Volume 63 (1951) and later address the Society.

PERMISSION TO REPRINT

All material published in the JOURNAL, except the articles which are prefaced with an "Acknowledgement," are copyrighted by the American Society of Naval Engineers.

Permission is granted to reprint any copyrighted material contained herein if the following conditions are met:

a) The article is reprinted in full. Extracts or summaries or condensations may be printed with the consent of the author.

b) Credit is given to the JOURNAL with reference to the issue.

c) Credit is given to the author.

d) If the author is a military officer or a civilian employee of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

APPLICATION FOR MEMBERSHIP

IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

(See reverse side for required qualifications for various classes of membership)

Date _____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $10.00 as my annual membership dues for the year _____, $8.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

For Naval Membership

Name _____
(First) (Middle) (Last)

Rank _____ File No. _____

Business connection and position, if any _____

For Civil Membership

Name _____
(First) (Middle) (Last)

Years in engineering work _____

Years in responsible charge of important work _____

Present business connection and position _____

Recommended by (two members) _____

_____

For Associate or Junior* Membership (Delete One)

Name _____
(First) (Middle) (Last)

Rank, if Commissioned Officer of U. S. Army or of foreign military or Naval service _____

Date of Birth (For Juniors Only) _____

Business connection and position _____

Recommended by (one member) _____

_____
Signature of Applicant

*Submit only $6.00 for Junior membership

Address for JOURNAL and Mail

_____

_____

MAIL TO SECRETARY-TREASURER
THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.
Suite 403 Continental Building
1012 14th Street, N.W., Washington 5, D.C.

Company Memberships NOT Available

QUALIFICATIONS FOR MEMBERSHIP

Commissioned and ex-commissioned officers, warrant and ex-warrant officers, and reserve (commissioned and warrant) officers, of the Navy, Coast Guard and Marine Corps, of the United States, active or retired, shall be eligible as Naval Members. Persons eligible as Naval Members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as Civil Members. They shall have been in the active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school on engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as Civil Members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as Associate Members. Commissioned officers of the United States Army, United States Air Force and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army, of the United States Air Force, and of foreign naval and military services, the recommendation of a member will not be required.

The annual dues shall be $10.00, payable on 1 January in advance of which $8.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

Any person eligible for either Naval Membership or Civil Membership, except for the experience requirement, and is less than 30 years of age shall be admitted as Junior Members at $6.00 per year.

Undergraduates at schools to be named by and under regulation to be issued by the Council shall be admitted as Student Members at $3.00 per year.

The transition from Student to Junior to Regular Membership in the appropiate category shall be automatic unless request to terminate membership be made in writing prior to the transition date.

Associate, Junior and Student Members shall be entitled to all the privileges of other members except voting and holding office.

Secretaries of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Captain J. E. Hamilton, U. S. Navy Retired, Secretary-Treasurer

Commander Joe W. Thornbury, U.S.N., Assistant Secretary-Treasurer

---

Past Secretaries

1889 *P. A. Engineer R. S. Griffin, U. S. Navy*

1890 *Assistant Engineer W. M. McFarland, U. S. Navy*

1891 *Assistant Engineer Emil Theiss, U. S. Navy*

1892-93 *P. A. Engineer W. M. McFarland, U. S. Navy*

1894-95 *P. A. Engineer R. S. Griffin, U. S. Navy*

1896-97 *P. A. Engineer F. C. Bieg, U. S. Navy*

1898 *P. A. Engineer W. M. McFarland, U. S. Navy*

1899 *Chief Engineer A. B. Willits, U. S. Navy*

1900 *Lt. Comdr. A. B. Willits, U. S. Navy*

1901 *Lieutenant B. C. Bryan, U. S. Navy*

1902 *Lieutenant C. W. Dyson, U. S. Navy*

1903 *Lt. Comdr. John R. Edwards, U. S. Navy*

1904 *Lieutenant M. E. Reed, U. S. Navy*

1905 *Lieutenant W. W. White, U. S. Navy*

1906 *Lieutenant C. K. Mallory, U. S. Navy*

1907-08 *Lt. Comdr. T. C. Fenton, U. S. Navy*

1908-10 *Lieutenant H. C. Dinger, U. S. Navy*

1911 *Commander U. T. Holmes, U. S. Navy*

1912 *Lieutenant John Halligan, U. S. Navy*

1912 *Lt. Comdr. E. L. Bennett, U. S. Navy*

1913 Lieutenant O. L. Cox, U. S. Navy

1914 *Lt. Comdr. H. C. Dinger, U. S. Navy*

1915-16 *Lieutenant A. T. Church, U. S. Navy*

1917 Lt. Comdr. J. O. Richardson, U. S. Navy

1917-19 *Lt. Comdr. F. W. Sterling, U. S. Navy*

1919-21 Commander J. S. Evans, U. S. Navy

1921-23 Commander S. M. Robinson, U. S. Navy

1924-25 *Admiral Bryson Bruce, U. S. Navy*

1926 Commander A. M. Charlton, U. S. Navy

1927-28 Commander H. B. Hird, U. S. Navy

1928 Captain O. L. Cox, U. S. Navy

1929-30 *Commander H. T. Smith, U. S. Navy*

1931 Captain O. L. Cox, U. S. Navy

1932 Commander H. F. D. Davis, U. S. Navy

1933-34 Commander H. B. Hird, U. S. Navy

1935-36 *Commander C. S. Gillette, U. S. Navy*

1936-38 Commander Roger W. Paine, U. S. Navy

1938-40 Lt. Comdr. Guy Chadwick, U. S. Navy

1940-44 Captain J. E. Hamilton, U. S. Navy

1945 Commander R. T. Sutherland, Jr., U. S. Navy

1945-48 Captain F. W. Walton, U. S. Navy

1948-51 Captain J. E. Hamilton, U. S. Navy

Past Assistant Secretaries

1939-40 Lieutenant Milo B. Williams (C.C.) U. S. Navy

1941-44 Lt. Comdr. Robert T. Sutherland, Jr., U. S. Navy

1945 Captain F. W. Walton, U. S. Navy

1945-47 Commander Floyd B. Schultz, U. S. Navy

1947-49 Commander C. H. Meigs, U. S. Navy

1949-50 Commander Frank C. Jones, U. S. Navy

1951-59 Captain Robert B. Madden, U. S. Navy

1959-60 Commander Charles N. Payne, U. S. Navy

Clerk and Administrative Assistant

1908-58 Mr. Arthur G. Fessenden

1958- Miss Ruth M. Leonard

---

*Names in italics deceased

NOVEMBER 1961

TABLE of CONTENTS

		Page
SECRETARY'S NOTES		643
Exotic Power Sources	THORNBURY	647
Bath Iron Works	NEWELL	655
Automation for Ships	Reprint	665
Colidar	Reprint	681
Navy Development of Radio	JAMES	685
Needs in Review	Reprint	693
Soviet Engineering Notes	KASSELL	697
Gas Turbine Boost Propulsion	Reprint	709
Understanding Automatic Control	BRALEWSKI	715
Automatic Boiler Control	Reprint	719
Hardened and Ground Gears	Reprint	727
Plasma Pinch Engine Experiments	GRANET & GUMAN	745
Electromagnetic Compatibility	Reprint	763
Heat Exchanger Systems Design	SCHENCK	767
Steam Requirements	KAUFMAN & SEGALO	773
Plastics for Hydrospace Vehicles	Reprint	775
C. P. Bow Thrusters	PEHRSSON & MENDE	787
Superconductivity	Reprint	797
Shipbuilding Costs	Reprint	803
DEPARTMENTS		809